A STUDY OF TRAIL DEGRADATION ALONG THE PAT SIN RANGE, NORTH NEW TERRITORIES, HONG KONG

by

LEUNG, Yu-fai

Thesis submitted to the Graduate School
of the Chinese University of Hong Kong
in partial fulfilment of the requirements
for the degree of Master of Philosophy

June, 1992

Division of Geography
Graduate School
The Chinese University of Hong Kong

ABSTRACT

"A Study of Trail Degradation along the Pat Sin Range, North New Territories, Hong Kong"

Thesis submitted by LEUNG, Yu-fai
for the degree of Master of Philosophy
at the Chinese University of Hong Kong in June 1992.

The objectives of this study were to document the degradation condition and to investigate the environmental controls on trail degradation along the Pat Sin Range in the New Territories of Hong Kong. Fifty-eight sample sites were systematically located on the Pat Sin Range Trail between Hsien Ku Fung and Ping Fung Shan, passing over both volcanic and sedimentary rocks. The trail condition was assessed by a series of parameters indicative of the compaction and morphology of the trail, as well as by overview ratings. Inherent site conditions, including soil properties and locational variables, were recorded and determined.

The trail under study was generally in good condition, except for a noticeably wide tread. Serious site degradation was observed at only a limited number of localities.

Trail compaction was generally associated with soil properties, especially those indicative of soil texture. Slope steepness was found to be the most influential factor

in the morphological degradation of the trail, though trail incision was also related to the fine texture of the soil. Trails aligned parallel with terrain slopes were degraded more frequently, especially at upper slope positions on landscape developed from volcanic rock.

Site conditions were significantly different between volcanic and sedimentary rock types, but the overall condition of trail degradation did not vary significantly between the two rock types. The nature of the slope-degradation relationship varied between parent rocks. Whilst trail degradation did not show a conspicuous association with slope steepness on the sedimentary rock, the slope-degradation relationship of the trail was more clear and generally exponential on the volcanic rock.

The findings of this research suggest that in trail planning and management, particular attention should be placed on steep direct-ascent trails as well as trails which traverse volcanic rocks where degradation may be more profound if the trails are initially inappropriately located.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my supervisor, Dr. Ronald J. Neller, for his advice in selecting the research topic. His patient guidance, continuing support and warm encouragement go well beyond his academic role. I am also indebted to my co-supervisor, Dr. Kwai-cheong Chau, for his invaluable comments and suggestions on the laboratory work and the thesis.

The expense of research was partially supported by the Student Campus Work Scheme of Shaw College of the Chinese University of Hong Kong and is hereby acknowledged. The kind approval from the Agriculture & Fisheries Department of Hong Kong Government made field sampling possible.

I should also express my appreciation to Dr. Michael J. Liddle for his comments and keen interest in my field sites when he visited Hong Kong last summer.

The contents of the thesis were significantly substantiated by the useful comments and generous provision of valuable literature from the following people and institutions:

(1) Dr. Jeffrey L. Marion and other staff of the research stations of the National Park Service of the U. S. Department of Interior;

(2) Dr. David N. Cole, Dr. Thomas A. More and other staff of the research stations of the Forest Service of the U. S. Department of Agriculture;

(3) Dr. Neil G. Bayfield of the Nature Conservancy of the United Kingdom;

I must also acknowledge the assistance of some overseas colleagues, including Messrs. Kwok-chung Chu, Sai-leung Ng and Chun-kwok Wong, in obtaining library material.

Thanks must be extended to the following colleagues for their cordial and indispensable assistance in field and laboratory work. They include Mr. Man-kam Chee, Mr. Kwok-keung Ho, Miss Tsz-nei Foo, Miss Man-yee Chan and Miss Miu-han Wong. Other support included Mr. Fung-wai Lui for his help in the laboratory, Miss Eva Yee-man Yip, Mr. Hok-wai Choi and Miss Maggie Man-kei Ma for their help in map drawing and other miscellaneous work.

Last, but surely not least, the encouragement and patient support from Miss Laura Suet-Lai Lam must be gratefully acknowledged.

TABLE OF CONTENT

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure		Page

LIST OF PLATES

CHAPTER I

INTRODUCTION

THE PROBLEM

The Country Parks of Hong Kong

Although the recreational use of natural or semi-natural areas can be traced back to the last century, the high contemporary demand is a social phenomenon that occurred only after the Second World War (Green, 1985; Cordell et al., 1990). The popularity of outdoor-recreation pursuits can be attributed partly to the transformation of socio-economic structure and life styles associated with increasing time, mobility and affluence, and partly to a growing interest and awareness of the outdoors and the natural environment.

Whilst the demand for outdoor recreation is more prominent in western countries, Hong Kong is no exception. Participation in recreational activity outdoors, such as sightseeing, picnicking, camping, hiking and leisure walking, has increased steadily in Hong Kong over the same period (Fong-Lee, 1982; Wholey, 1978; Ng, 1986).

In view of the burgeoning demand for countryside recreation, as well as the need to control the abuse of countryside resources, the Hong Kong Government initiated efforts in the 1960s and 1970s to establish a country parks system as advocated by the consultants and advisory committees (Talbot & Talbot, 1965; Hong Kong Government, 1968). The programme culminated in 1976 with the enactment of the Country Parks Ordinance (Hong Kong Government, 1986). Twenty-one country parks were designated under the provisions thereafter, covering about 40000 hectares, or 40 percent of the land area of Hong Kong. These parks generally possess high scenic quality and most of them are situated at remote or hilly areas, mainly in the New Territories and the outlying islands (Thrower, 1984).

The establishment and promotion of country parks further attracted and encouraged their recreational use (Fong-Lee, 1982). The number of visitors to the country parks has tripled during the last decade, with only a transient slack in the mid-1980s (Agriculture & Fisheries Department, 1977-1991). In the 1989/1990 Financial Year, there were 9.26 million visitors to the country parks, a notional average of 1.6 visits per person or 22400 visits per km^2 park area (Agriculture & Fisheries Department, 1991). This is a high level of use considering the limited areal and resource base of the parks.

Apart from providing informal recreational outlets for urban inhabitants, the Country Parks Programme aims simultaneously to protect the nature of countryside and to provide statutory control of urban expansion (Lau, 1991). Unfortunately, but not surprisingly, the recreational use of the countryside has occasionally been in conflict with these conservation objectives, as both are essentially pursuing the same resources.

Resource Impacts of Country-Park Recreation

The high level of visitation to these country parks has caused detrimental impacts upon the resource components that constitute the very environment to which the visitors resort. Fire, trampling, littering and vandalism are major impact forces (Jim, 1986). The problem is further exacerbated by the uneven patterns of patronage, both spatially and temporally, amongst the country parks (Fong-Lee, 1984; Jim, 1989a).

Resource impacts in the country parks generally take on one or a combination of three patterns: point, linear and areal deterioration. The use-intensity zoning within the country parks [1] (Wong, 1988) has led to problems of over-use and resource degradation at the 'honey-pot' recreational sites in intensively used zones (Jim, 1987a & 1987b). There is also areal destruction of vegetation and

[1] The country parks are informally divided into recreation, wilderness and conservation zones where different intensity of facilities and management input are allocated to serve different intensity of use.

landscape by hill fires in the parks (Thrower, 1984). The emphasis of this research, however, is on the patterns of linear deterioration.

Trail Degradation

Linear deterioration patterns generally occur as a result of footpaths and trails. In fact, though footpaths and trails are the main travel arteries in country parks, many of them were created by villagers for convenience rather than with recreation or resource protection in mind (Thrower, 1975).

Trail degradation appears to be a world-wide resource management issue in natural or semi-natural areas since it represents depletion of a non-renewable resource (i.e. soil loss) and a failure to maintain the natural character of an area. Degraded trail treads and proliferated tracks can be an eyesore for visitors and detract from their recreational experience. More practically, footing on incised paths is unpleasant, if not unsafe. Such paths are also costly to maintain due to the large area and rough terrain involved.

The problem of footpath erosion in Hong Kong was first noticed by Berry (1955), and it has been mentioned recurrently (Grant, 1960; Hong Kong Government, 1968; Thrower, 1975; Hansen & Nash, 1985; Jim, 1986, 1987c & 1989b). Nevertheless, research devoted to this problem is negligible. The lack of local information on trail degradation precludes any evaluation of the nature and severity of the problem. As Boden (1977) stated:

> "One of the difficulties in assessing the potential environmental or ecological effects of any proposed recreational development is the lack of research data for local conditions and assessment of past effects as a guide to the future" (Boden, 1977: 225)

The increasing evidence of trail degradation in local country parks calls for objective investigations of this topic. Assessment of trail condition and environmental vulnerability is a worthwhile and necessary step in developing guidelines and priorities for judicious management, maintenance and planning of trails (Cole, 1983a; Leonard et al., 1977).

OBJECTIVES OF THE STUDY

Recognizing the above-mentioned need, the present study attempts to explore the problem of trail degradation in Hong Kong. A popular hiking trail in the Pat Sin Leng Country Park, which is located in the northern New Territories, was selected as the study area. The specific objectives of the study are:

(1) To quantitatively document the nature and extent of degradation on the study trail;

(2) To account for the differences in degradation level along the study trail using environmental site characteristics;

(3) To examine the implications of trail degradation for trail planning and management based on these research findings.

SCOPE OF THE STUDY

While the present study is by no means a thorough one, it seeks to address some basic questions regarding the situation of trail degradation in the local physiographic environment.

During the discussion throughout the thesis, terms such as 'path', 'footpath', 'track' and 'trail' may be used interchangeably and generally share a similar meaning: this being the visual imprint of animals (including human) in the intervals between their successive movement along a route (Huxley, 1970). However, the term 'trail' as used here specifically refers to that path or track which is unsurfaced, so that its degradation should be the result of the characteristics of site durability, use pressure and management input.

Degradation here refers to only the 'physical degradation' on trails: compaction, widening, incision, erosion and multiple treads, as they are thought to be the more imminent and discernible problem in the park environment rather than the inconspicuous alteration to the vegetation community. Accordingly, no attempt was made in the present study to examine the impacts on vegetation, though it has attracted considerable attention in studies conducted in Europe and North America.

Due to a number of logistic constraints, the present study investigates several types of degradation along only one trail route, and will focus on only the cross-sectional or spatial aspect of degradation. A longitudinal or temporal perspective is beyond the scope of the present study, but that future research should address this perspective is imperative.

The thesis consists of eight chapters. The first four chapters provide the necessary background as well as an appraisal of previous studies. Methods and techniques employed in the present study are also illustrated. Chapters V and VI outline the results of this study, and those findings which may be useful for trail planning, management and maintenance will be discussed in Chapter VII. Chapter VIII summarizes the limitations and conclusion of the study as well as suggestions for future research.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

Ecological effects of recreational activities have long been recognized in North America and Western Europe (Speight, 1973). Indeed, as early as the 1930s, Bates (1935) conducted observations and experiments examining vegetational gradients across trails, and survival strategies of trailside plant species under trampling pressure.

It is a matter of fact that any walking or riding on trails will inevitably exert trampling pressure upon the trail tread as well as the trailside environment. The definition of trail already connotes the intrinsic difference between a trail and its vicinity (Huxley, 1970). Nevertheless, research on trail deterioration, like other topics in recreation ecology, has been given priority only since the late 1960s (Goldsmith, 1985; Cole, 1987). At present, many resource managers (Cole et al., 1987), as well as the public (Lucas, 1985), consider trail impacts as a common management problem in wilderness, national parks and natural areas alike.

In response to such concerns, systematic and quantitative investigations on this topic were carried out and a body of literature has subsequently accumulated (Cole & Schreiner, 1981). The current state of knowledge on recreation ecology, in which trail impact research is a major component, has been reviewed by Cole (1987), Liddle (1988 & 1989) and Kuss et al. (1990).

Despite the diverse volume of literature, the following review, except for the section entitled Research Approaches, will focus only on those aspects pertinent to the physical degradation of trails. The sequence of review is also arranged according to the structure of the thesis.

RESEARCH APPROACHES

There are various approaches and emphases that have been used in trail impact studies. Some have examined the effects of specific activities on trails, such as walking (Burden & Randerson, 1972) and off-road vehicles (Slaughter et al., 1990), or have compared the impacts resulting from different activities (Weaver & Dale, 1978). Other studies have assessed trail impacts on various resource components, such as vegetation (Cole, 1978), soil (Fish et al. , 1981) and soil fauna (Duffey, 1975). Another type of study focuses on the environmental factors which affect site susceptibility to impacts by trail use (Helgath, 1975).

The variety of research emphases can generally be grouped into two approaches, namely comparative and experimental, under each of which further divisions and sub-divisions are classified (Table 2.1). However, no classification is entirely satisfactory and there have been studies which integrate (sub-)divisions or approaches; as for instance, a comparison amongst sites could be re-measured at a later time to assess the temporal change of the sites (Summer 1980 & 1986; Cole 1983a & 1991).

Table 2.1 The approaches of trail impact study.

Approach	Example(s)
Comparative	
Cross-Sectional Study	
undisturbed VS disturbed	Cole (1978); Hall & Kuss (1989)
comparison among sites	Helgath (1975); Bryan (1977); Coleman (1981)
Longitudinal Study	
change on established trails	Lance et al. (1989); Cole (1991)
change following trail creation	Garland (1987)
change following trail closure	Boucher et al. (1991)
Experimental	
Human trampler	Weaver & Dale (1978); Leonard et al., (1985)
Artificial trampler	Bayfield (1971)

Source: Based on Marion & Cole (1989).

It is generally agreed that longitudinal or experimental studies following trail creation are the most rigorous approaches for impact research, but the long duration required, unreal simulation and few newly-created trails preclude their widespread application (Cole, 1987).

For these reasons, the comparative approach has been adopted in many studies (Wall & Wright, 1977). However, with the comparative approach the magnitude of recreational impacts cannot be fully assessed as the base level of the environment before recreational use is usually difficult to reconstruct. It is also hard to disentangle the importance and role of each of the many human and environmental variables involved. Many recreational impacts, such as trail erosion, may be essentially the outcome of normal slope processes whose actions are exacerbated by human use.

Notwithstanding such limitations, comparative trail studies are considered to be capable of providing valuable information for developing more judicious and defensive guidelines for trail management practice even before the advent of models with predictive capabilities (Kuss & Morgan, 1984; Morgan, 1985).

PHYSICAL DEGRADATION ON TRAILS

Amongst the impact studies to date, including those associated with trails, a great deal of attention has been given to the alteration of vegetation elements. Some generalizations on morphological and anatomical adaptation and survival strategy of plants have also been developed (Kuss, 1986; Liddle, 1991). In contrast, the physical degradation of trails has received less attention (Quinn et al., 1980; Kuss et al., 1990), though bare eroding paths are often functionally and aesthetically more important than the loss or change of a few plant species (Goldsmith, 1974; Cole, 1983a).

Table 2.2 summarizes the common trail impact problems encountered in the United States. Whilst all of these problems can also be found in Hong Kong's country parks, some would appear to be more acute in Hong Kong's trail environment which characterized by openness, low altitude but high steepness, and intense rainfall. A major cause of the listed problems is improper location of trail segments on vulnerable sites. Accordingly, improving location and hardening tread seem to be the main strategies to arrest these problems.

Table 2.2 Common trail impact problems, and strategies and techniques for mitigating such problems.

Problem	Strategy	Technique (example)
Erosion	Improve location/design	Build water bars
Muddiness	Improve location/design	Route trails around boggy areas
Multiple trails	Improve location	Relocate trails
Shortcutting switchbacks	Change user behaviour	Convince visitors to stay on existing trails
Informal trail systems	Reduce use	Reduce use quotas

Source: Cole (1990)

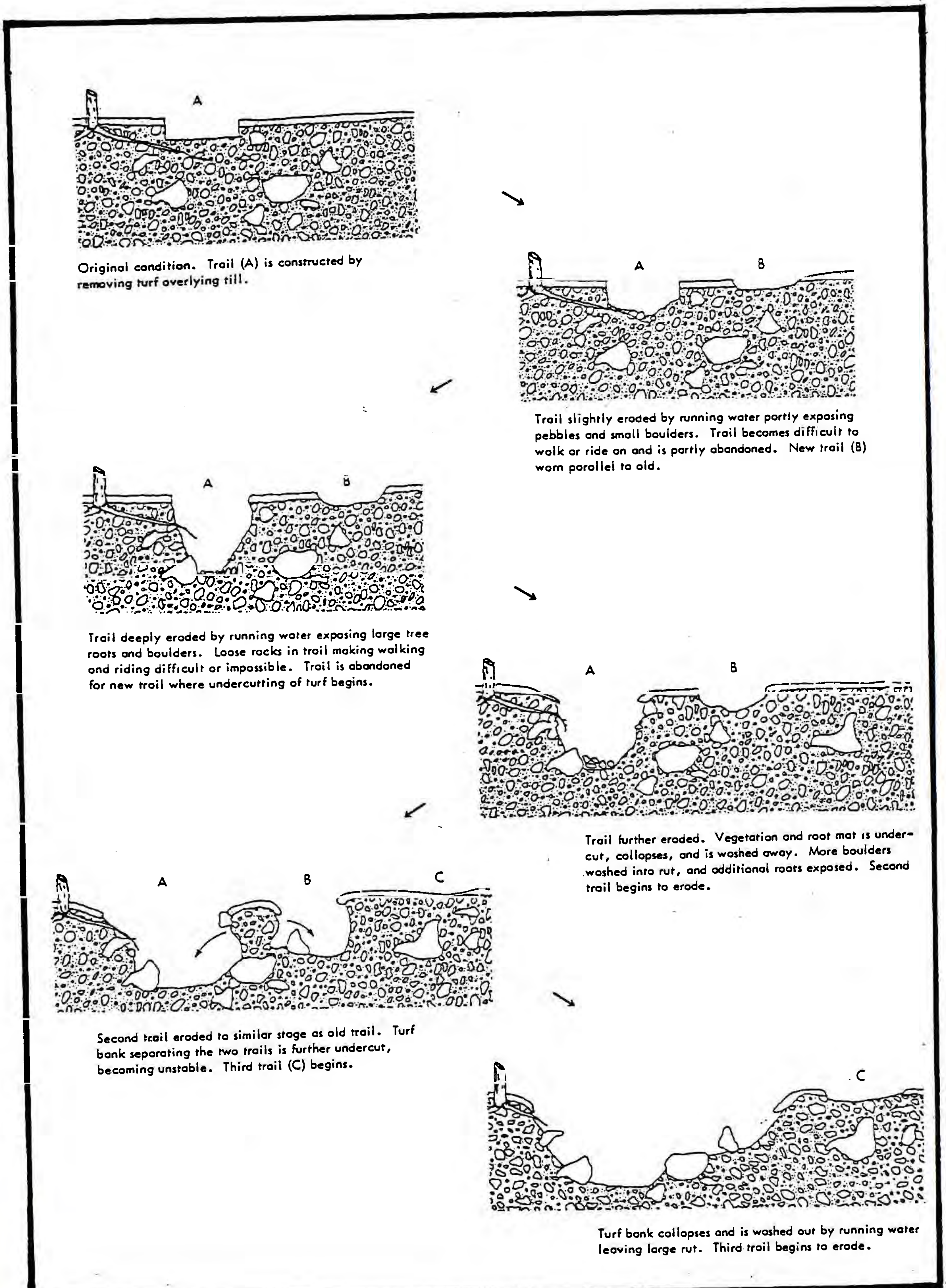
The physical degradation of trails generally comprises compaction, widening (including multiple parallel treads), incision and erosion of the tread surface. In addition to these problems, trail deterioration also comprises the proliferation of switchback shortcuts, impromptu trails and other kinds of informal trail systems which appear to be of concern to research workers in the United Kingdom (Aitken, 1985, Bayfield, 1986).

The degradation process of a trail is illustrated in Figure 2.1. The combined effects of human footfall and of running water seem to be the predominant forces of degradation. Degradation generally originates with incision and/or muddiness of the tread surface. When a trail is incised to a level at which users feel uncomfortable to either walk or ride on, they will wander off and travel on adjacent trailside zones, causing further destruction of the trail by increasing the bare ground of tread or creating multiple parallel treads.

Compaction

Compaction, an increase in soil density, is an inevitable result of trail use. Indeed, it is a common practice to compact the trail treads purposely in order to stabilize the surface materials (Proudman & Rajala, 1981; Lucas, 1984). That compaction can reduce porosity, permeability and infiltration capacity of a soil are well documented (Barnes et al., 1971). Such changes are liable

Figure 2.1 Graphical presentation of the trail degradation process.



(Source: Root & Knapik, 1972)

to impede plant root penetration and provoke a greater runoff volume on the tread surfaces that in turn leads to accelerated erosion.

Soil compaction on trails is normally measured using bulk density or penetrability (Liddle, 1989). Studies have shown that trail use can lead to an increase in bulk density by 0.04 g/cm^3 (4% increase) in chalk grassland (Chappell et al., 1971) to as much as 0.44 g/cm^3 (46% increase) in glacial till (Dawson et al., 1974).

Owing to the convenience and sensitivity of measurement, penetrometers of varied types have frequently been employed in trail impact studies (e.g. Liddle & Greig-Smith, 1975; Crawford & Liddle, 1977; Hall & Kuss, 1989). However, the results of penetration resistance are not strictly comparable to those of bulk density or even to those measured in different moisture regimes (Liddle, 1989).

Widening and Incision

As illustrated in Figure 2.1, poor footing conditions on tread surfaces probably leads to treading on trailside areas or the creation of multiple treads alongside, which may eventually collapse and fuse into a single wide tread. Continued use can induce retreat of vegetation adjacent to the treads by direct killing or harsh soil conditions, resulting in an increase in bare width of treads.

In the Cairngorm Mountains in Scotland, Bayfield (1985) found that nearly all paths showed substantial increases in width and bare ground between 1971 and 1983. Lance et al. (1989) reported that footpaths in the same region widened 0.2 to 1.3 metres in 5 years.

Results of previous studies indicate that a change of trail width is most significant at the initial stage of use, especially in the lightly to moderately used trails (More, 1980; Leonard et al., 1985; Lance et al., 1989; Cole, 1991).

Incision goes hand in hand with widening, though the latter may largely be controlled by environmental rather than use factors (Coleman, 1981; Cole, 1991). In the Adirondack Mountains of New York, Ketchledge & Leonard (1970) estimated a trail to incise at a rate of 2.5 cm per year.

Erosion

Without the protection of vegetation cover, together with compaction and disruption of soil aggregate stability (Chappell et al., 1971), widened and incised tread surfaces are subject to direct impact of raindrops and runoff. The usual sequence of erosion: splash, sheet, rill and gully erosion can also occur along trails (Lal, 1992).

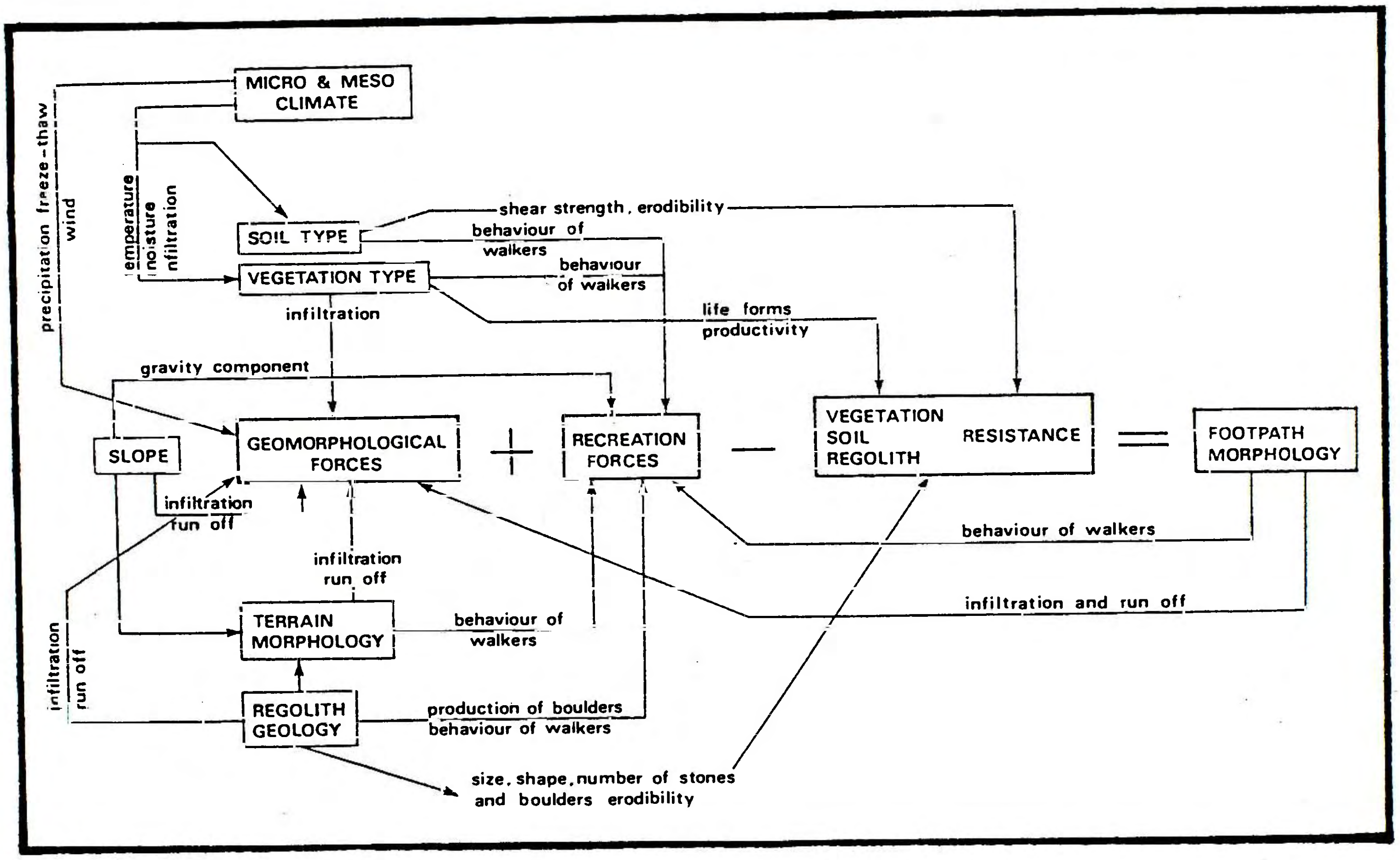
Trail erosion can be measured either by determining the volume of sediment it produces or by determining the dimensional loss of cross-section (Liddle, 1989). Examples of the former are Kuss (1986) and Garland (1987), and of the latter, Helgath (1975) and Cole (1983a & 1991).

The cycle of trail erosion that leads to deep incision (Helgath, 1975; Bratton et al., 1979), selective loss of fine earth (Starodubova, 1985), profile truncation (Bryan, 1977) and severe soil loss (Helgath, 1975; Cole, 1983a) has been well documented. One must remember, however, that although there are places where degradation problems are very serious, the trail system as a whole has often been found to be stable due to the complementary processes of erosion and deposition (Tinsley & Fish, 1985; Cole, 1991).

FACTORS CONTRIBUTING TO TRAIL DEGRADATION

Coleman (1981) has attempted to explain the intricate factors that affect trail degradation with a conceptual model (Figure 2.2). In general, there are three principal forces controlling the morphology of a trail: geomorphological forces, recreation forces and site resistance. The intensity of each force is further complicated by a series of interrelated factors. However, some factors may be subsumed by others or may be evaluated by their surrogates. For example, such capricious soil parameters as infiltration capacity and moisture may be reflected by more stable properties like soil type and

Figure 2.2 Possible factors and forces affecting the morphology of a path.



(Source: Coleman, 1981)

texture. In the following discussion, the relevant factors contributing to trail degradation are grouped into use and environment categories.

Use Characteristics

Many trail impact studies seek to examine the use-impact relationship (Cole, 1987; Liddle, 1989; Kuss et al., 1990). Use characteristics comprise intensity of use, type of use, as well as the behaviour of the user.

A curvilinear relationship between use intensity and several trail impact parameters, predominantly compaction (Chappell et al., 1971; Liddle & Greig-Smith, 1975) and trail width (Weaver & Dale, 1978; Lance et al., 1989), has frequently been identified. It is generally agreed that light to moderate use can lead to a considerable impact, and that a further increase in use would induce little additional damage.

The different degrees of damage caused by hikers, horses and vehicles have been examined by Dale & Weaver (1974), Liddle & Greig-Smith (1975), Whittaker (1978) and Weaver & Dale (1978). Most results support the perception that vehicles and horses are more damaging than hikers on trails.

Trail degradation is influenced by the behaviour of walkers as well. Weaver & Dale (1978) reported that downhill walking is more damaging than uphill walking. Bayfield (1973) found that walkers tend to wander off the original trail tread when they walked downhill.

Environment

The degree and rate of degradation of a trail is also influenced by the resistance of site that associated with its site characteristics. Factors that have already been evaluated include locational, pedological and vegetative factors.

Locational factors refer to the alignment of a trail on a slope, including the steepness of a trail and its underlying terrain, the aspect of both the trail and its terrain, and the position on a slope where the trail segment is situated. Amongst these variables, the steepness of the trail has often been identified as the main factor in controlling trail erosion - the most serious form of physical degradation (Helgath, 1975; Bratton, 1979; Coleman, 1981; Jubenville & O'Sullvian, 1987).

In an extensive trail condition survey in the Great Smoky Mountain National Park, Bratton et al. (1979) found that most of the trails that were oriented perpendicular to contours and with slopes greater than 10^0. were in poor condition. In the Lake District National Park of Britain, Coleman (1981) suggested a slope of $17\text{-}18^0$ as the threshold level for differentiating between eroding and non-eroding footpaths.

Some other locational variables, such as aspect (Dawson et al., 1974) and roughness on both the tread and the adjacent areas (Bayfield, 1973), were also identified as factors affecting trail degradation.

It has long been established that soil erodibility is closely related to its physical properties (Morgan, 1986). In the Swedish mountains, Bryan (1977) reported that trails in stone-free soils, with homogeneous textures, were invariably deeply incised, whilst trails on organic soils always became quagmires. The influence of parent material on trail condition was also revealed by Root & Knapik (1972), Burde & Renfro (1986) and Welch & Churchill (1986).

The nature of trailside vegetation can also influence physical degradation. Bayfield (1971), Dale & Weaver (1974) and Bright (1986) found that hikers were more likely to wander off the trail in open areas than off trails bordered by shrubs and trees. Such difference in user behaviour have resulted in wider trail treads in open areas.

RECREATION IMPACT STUDIES IN HONG KONG

Most recreation impact studies have been conducted in temperate regions. The topic of recreation ecology has been largely neglected by research workers in Hong Kong. In the contrasting physiography of subtropical Hong Kong, the strength and nature of the factors affecting such impacts may vary.

Jim (1987a & 1987b) has recently investigated the recreation impacts on vegetation and soil on the picnic areas and campsites in some heavily-patronized country parks. He reported a substantial loss of ground vegetation cover as well as pronounced changes in vegetation composition and soil characteristics at these recreation sites. These findings demonstrated the acute recreation-conservation conflict in the country parks.

Footpath erosion was recognized even earlier as a soil and water conservation problem. Berry (1955) described various types of footpath degradation in the countryside:

> "In the New Territories most of the footpaths take the easier route over the spurs, avoiding the steep irregular stream beds. Many of these well trodden paths become bare patches of earth or the already dried up slopes and they form small depressions as loose dust is blown or washed away. These small hollows form ready made water courses in the rainy season and considerable potholes can be seen developing on footpaths. In some cases these extended to become gullies which divert much water from the original stream" (Berry, 1955:68)

Only two projects focusing on trail impacts can be found, and neither has been published. Chan & Wu (1972) studied vegetation and soil impacts by trail use in Wu Kwai Sha in the New Territories. They reported lower soil moisture and humus content, and greater compaction of surface soil. A more detailed study conducted by Sum (1980) in the nearby Ma On Shan area also reported decreased soil moisture, aggregate stability and aeration on the path.

The findings of both studies are similar to those reported elsewhere, and there are clear implications for gully erosion along paths in the territory, especially those on slopes (Thrower, 1975).

To sum up, previous research has shown that physical degradation on trails can be influenced by numerous use and environmental factors, and there is evidence that trail degradation is more likely to be affected by user type and their behaviour, rather than by the intensity of use alone.

Previous studies also suggest that differences in degradation are largely the result of varying environmental and locational factors (Cole, 1987; Hammitt & Cole, 1987; Kuss et al., 1990). This is particularly applicable to trails which are long-established and well-trodden.

CHAPTER III

STUDY AREA

INTRODUCTION

Hiking and leisure walking are popular outdoor recreational activities in Hong Kong. A recent visitors survey ranked hiking and leisure walking as two activities second only to barbecuing in popularity in the country parks (Country Parks Authority, 1988). Amongst the first-rate hiking routes in the territory, the trail which traverses the ridges of the Pat Sin Range (the PSR Trail hereafter) attracts much interest from hikers who seek panoramic views and a wildland hiking experience (Chan, 1979; Law, 1983; Chu, 1991).

Endowed with outstanding landscape and geological legacy, the Pat Sin Range inside the Pat Sin Leng Country Park has been designated as a 'special area' under the Country Parks Ordinance to highlight its conservation value (Hong Kong Government, 1986). Also because of its fame, the PSR Trail are at the cost of withstanding heavy use pressure.

THE PAT SIN LENG COUNTRY PARK

The Pat Sin Leng Country Park is located in the northern part of the New Territories (Figure 3.1). It is the fifth largest country park in the territory, covering an area of 31.25 km^2 (Figure 3.2).

Topography, Geology and Soils

The Pat Sin Leng Country Park features an escarpment known as the Pat Sin Range which comprises the ridges of Pat Sin Leng, Lai Pek Shan, Wong Leng, Ping Fung Shan and Shek Au Shan. The ridges rise dramatically from the northwest shores of Tolo Harbour, but slopes are much gentler on the northern side.

The Pat Sin Range area is underlain by both volcanic and sedimentary rocks (Figure 3.3). The southern slopes of the Range are underlain by volcanic rocks of the Tai Mo Shan Formation of the Repulse Bay Group formed in the Upper Jurassic-Lower Cretaceous Period. Coarse ash crystal tuff is the major type of volcanic rock. Along the northern slopes, sedimentary rocks deposits usually overlie these volcanic rocks. They were formed in the Lower Cretaceous Period as part of the Pat Sin Leng Formation. Purplish to brick red sandstone and siltstone, gleyish white sandstone and conglomerate are the major rock types (Geotechnical Control Office, 1988 & 1991).

The bedrock in the study area has been subject to severe weathering, and weathering processes on the

Figure 3.1 Location of the Study Area.

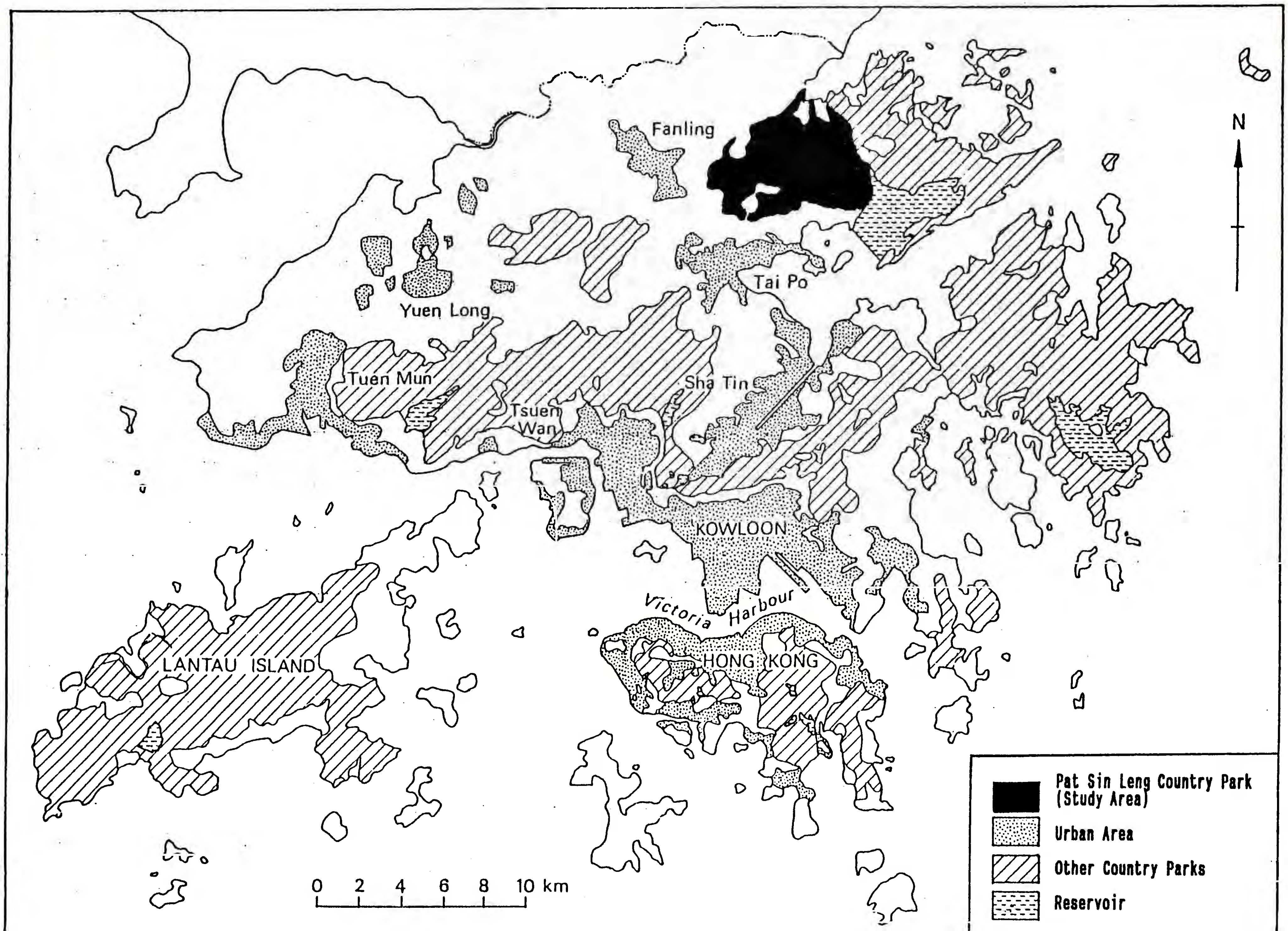
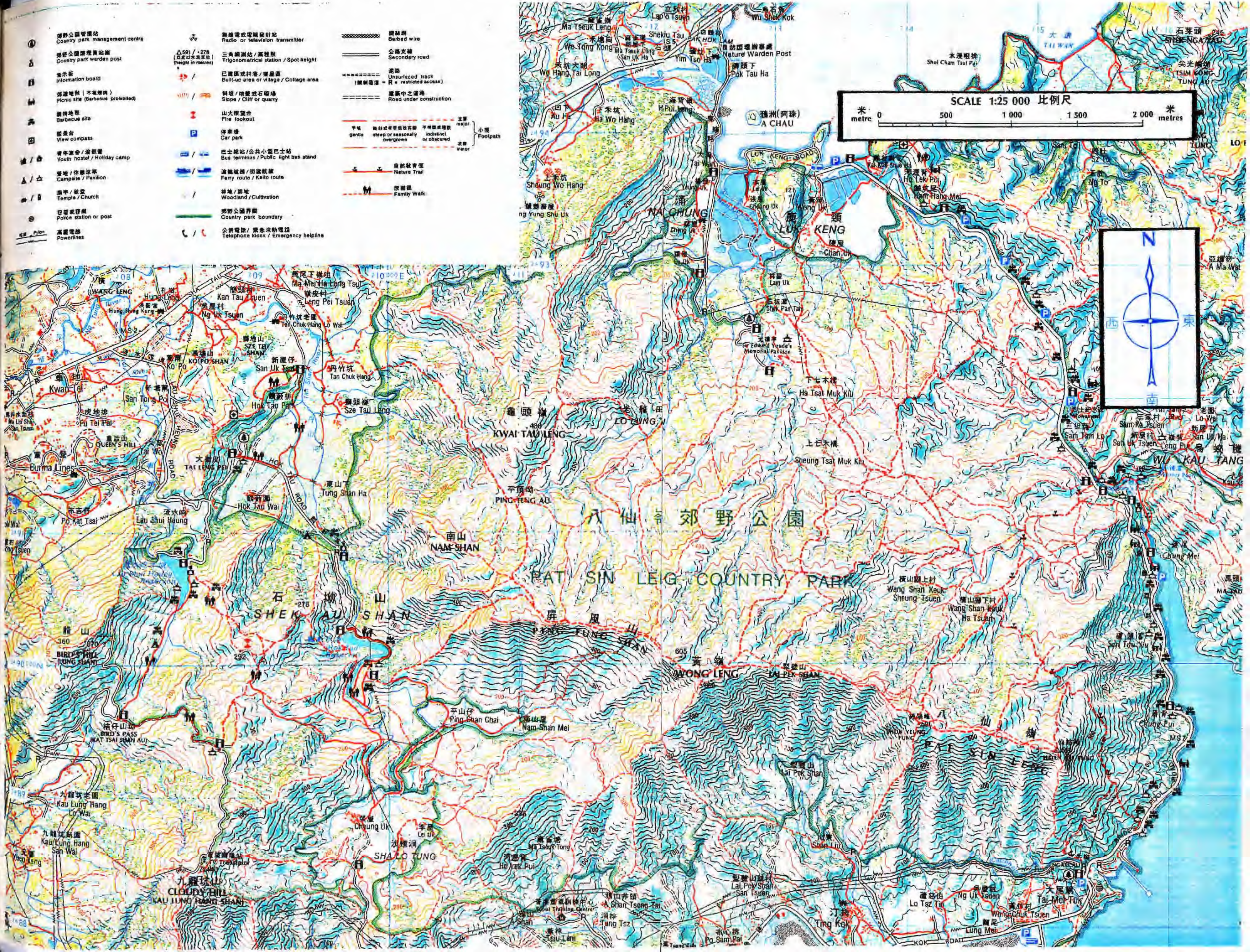
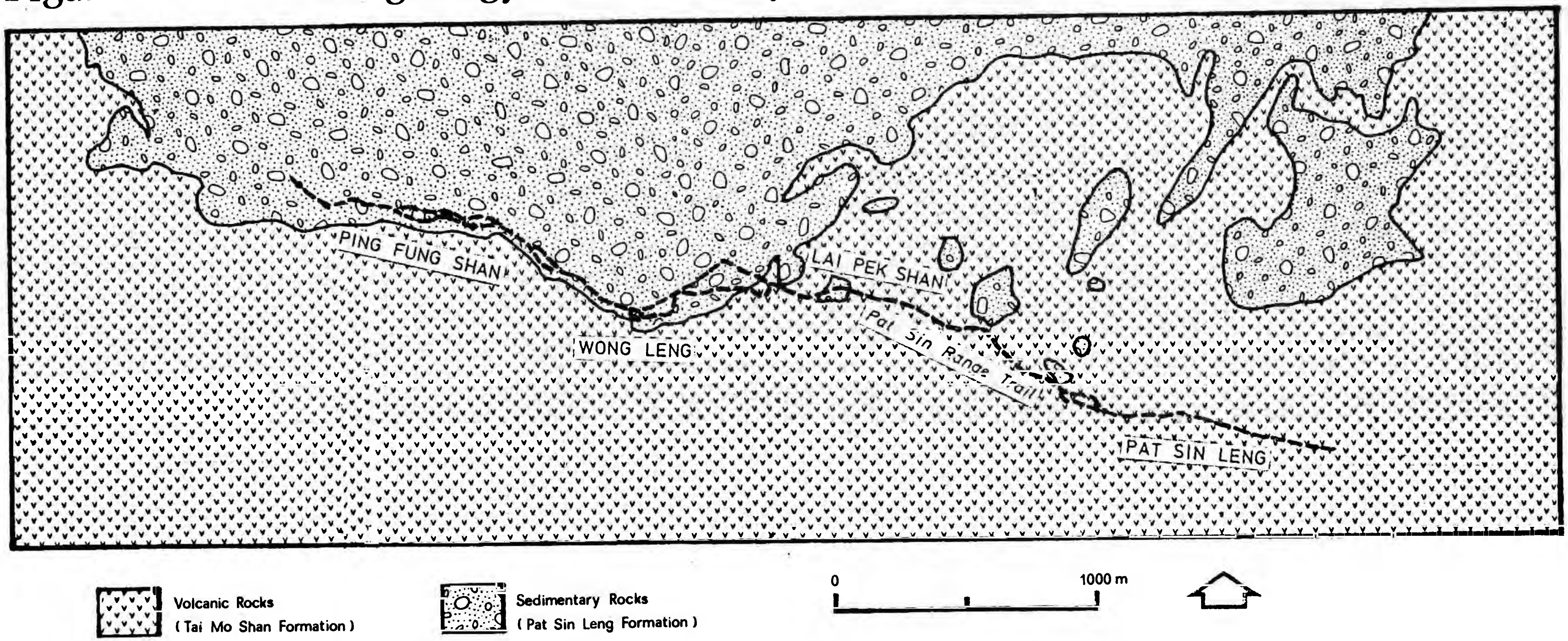


Figure 3.2 The Pat Sin Leng Country Park.
(Source: Survey & Mapping Office, 1991)



Country park management centre
Country park warden post
Information board
Picnic site (Barbecue prohibited)
Barbecue site
View compass
Youth hostel / Holiday camp
Campsite / Pavilion
Temple / Church
Police station or post
Pylon
Powerlines
Radio or television transmitter
Trigonometrical station / Spot height
(height in metres)
Built-up area or village / Cottage area
Slope / Cliff or quarry
山火瞭望台
Fire lookout
Car park
Bus terminus / Public light bus stand
Ferry route / Kaito route
Woodland / Cultivation
Country park boundary
Telephone kiosk / Emergency helpline
Barbed wire
Secondary road
Unsurfaced track
R = restricted access
Road under construction
gentle
steep or seasonally overgrown
indistinct or obscured
major
minor
Footpath
Nature Trail
Family Walk
SCALE 1:25 000 比例尺
米 metre
米 metres
0
500
1 000
1 500
2 000
N
西
東
南
八仙嶺郊野公園
PAT SIN LENG COUNTRY PARK
KWAI TAU LENG
PING FUNG SHAN
WONG LENG
NAM SHAN
SHEK AU SHAN
LUK KENG
NAI CHUNG
A CHAU
WU KAU TANG
CLOUDY HILL
SHA LO TUNG
BIRD'S HILL

Figure 3.3 Bedrock geology of the vicinity of the Pat Sin Range Trail.



(Source : Geotechnical Control Office, 1991) volcanic rocks are more active than those on the sedimentary rocks (Ho, 1971). As a result, the soil is better developed on volcanic rocks than on sedimentary rocks. Three types of soil are found in the country park: lithosol, red-yellow podsol and krasnosem, which are generally delimited by parent rock and elevation (Grant, 1960).

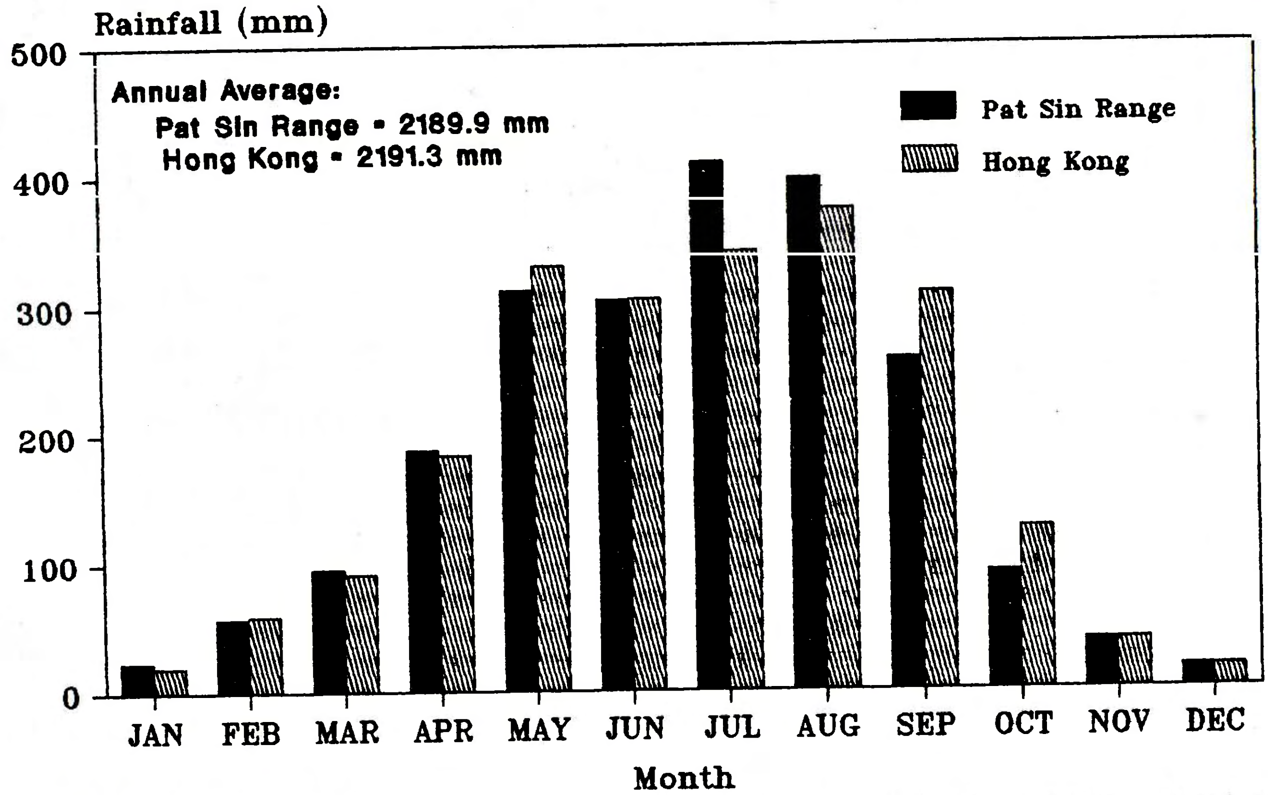
Climate and Vegetation

The climate of Hong Kong is subtropical and is dominated by monsoons (Chin, 1986). A cool and dry winter spans to November to February, whilst the hot and wet summer predominates from May to September, with a transitional short damp Spring and dry Autumn in between. Over 80 percent of the annual rainfall occurs during the summer months, and most is in form of heavy rains which are associated with tropical cyclones and troughs. On average, there are 26 and 12 days in a year with daily rainfall of 25 mm and 50 mm respectively (Chin, 1986). Unfortunately, meteorological records are not available for the study area. Rainfall records obtained for nearby rain gauges was found to be similar to that of Hong Kong (Figure 3.4).

Most of the park is covered with fire-climax grassland with patches of pine woodland, broad-leaved woodland and scrub which have so far escaped fire damage (Thrower, 1975; Thrower, 1984). There is close link between vegetation

Figure 3.4

Rainfall of the Pat Sin Range Area and the Hong Kong Territory, 1976 – 1990



Note: Rainfall data for the Pat Sin Range Area were compiled from the records of Chung Mei, Hok Tau & Tai Mei Tuk.
(Data Source: Hong Kong Royal Observatory, 1976 - 1991)

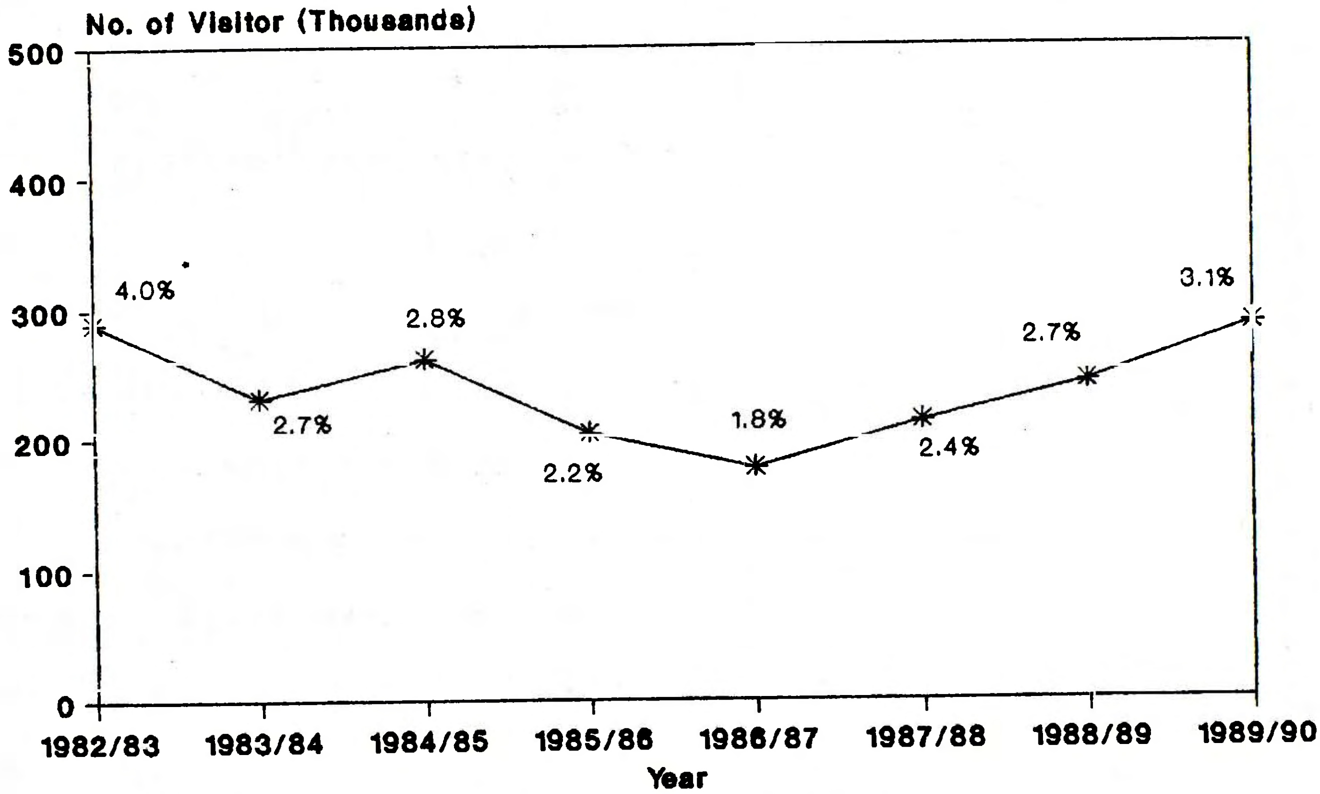
distribution and underlying soil-geology. On the volcanic rocks, the vegetation is dominated by the *Rhodomyrtus tomentosa - Arundinella nepalensis* Association. Shrub and grass species (e.g. *Ischaemum spp. Melastoma candidum*, *Eurya chinensis* and *Miscathus sinensis*) are sparsely distributed. On the sedimentary rocks, the dominant vegetation comprises the *Baeckea frutescens - Dicranopteris dichotoma* Association and the *Baeckea frutescens - Lepidosperma chinensis* Association. Shrubs and grasses are rather sparse here, with about 40 to 60 percent of areal coverage (Chang et al., 1989).

Recreation Use and Management

The 'wilderness-like' nature of the park possesses some of the most beautiful scenery in the territory. It provides a wide range of recreational opportunities and facilities: from picnicking, barbecuing, leisure walking and camping at the peripheral zone of the park to hiking and sightseeing along the rough ridge of the Pat Sin Range. In 1989/90, it attracted more than 3 percent of the total patronage to Hong Kong's country parks (Figure 3.5).

The provision, management and maintenance of recreational facilities inside the country park are the responsibility of the Agriculture and Fisheries Department

Figure 3.5
Patronage of the Pat Sin Leng
Country Park, 1982 - 1990



* = percentage in total patronage of H.K. country parks.
Data Source: Agriculture & Fisheries Dept. (1983-1991).

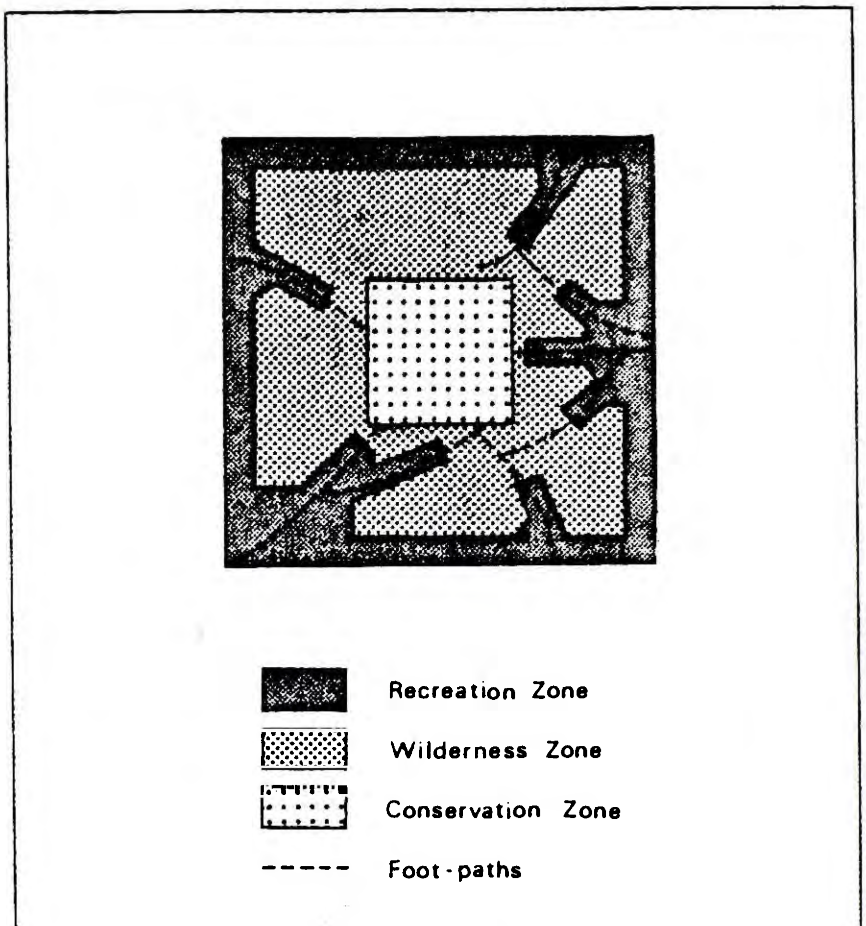
of the Government (Agriculture & Fisheries Department, 1991). The concept of recreation, wilderness and conservation zoning developed by the government has been implemented in the Pat Sin Leng Country Park (Figure 3.6). The high intensity area is located at the periphery of the park, whilst the conservation zone is situated in the middle. In between is the wilderness zone. In doing so, the impacts of picnicking and barbecuing are confined to the peripheral areas. Recreational impacts on the trails, however, extend over the entire park area, closely following the trail network.

The park is criss-crossed by numerous trails which fall into two general categories. Major trails are those which are well-established and used, but there are many other indistinct or lesser used trails named as minor trails. There are about 29 km of major trails in the park, with a density of about 940 m/km^2.[1] In addition, there are several trail segments designed for special use. Three 'Family Walks' are situated in the western part of the park. An interpretive 'Nature Trail' (the Pat Sin Leng Nature Trail) is also located at the footslope of the Pat Sin Leng and is connected to the PSR Trail.

---

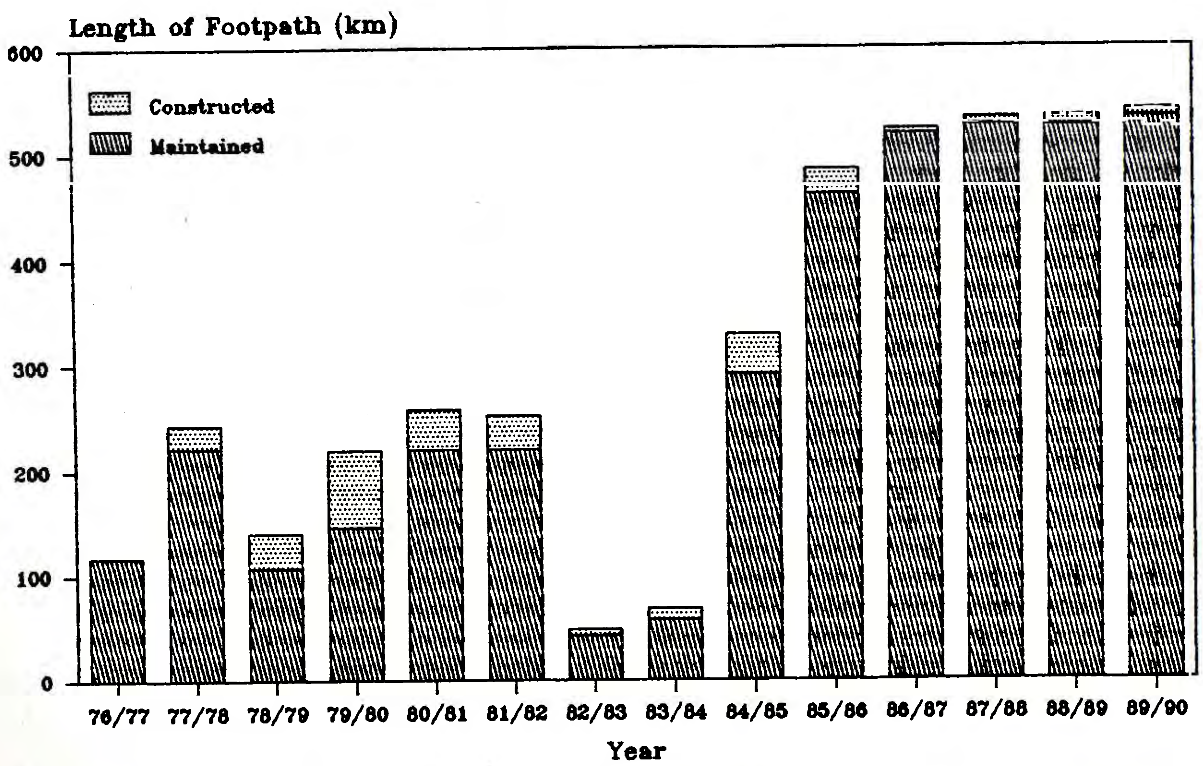
1 The total length of major trails is obtained using a chartometer (Gardiner, 1990).

Figure 3.6
Conceptual zoning of the
Pat Sin Leng Country Park.



Source: Fong-Lee (1982).

Figure 3.7
Footpath construction and maintenance
in the Country parks, 1976 – 1990



Data Source: Agriculture & Fisheries Dept. (1978-1991).

Most footpaths in Hong Kong's country parks are maintained rather than constructed (Figure 3.7). The priority of maintenance is generally given to those of easy accessibility and of interpretive use, such as the family walks and nature trails. In the Pat Sin Leng Country Park, most of the trails are located in the extensive zone and have a low maintenance priority.

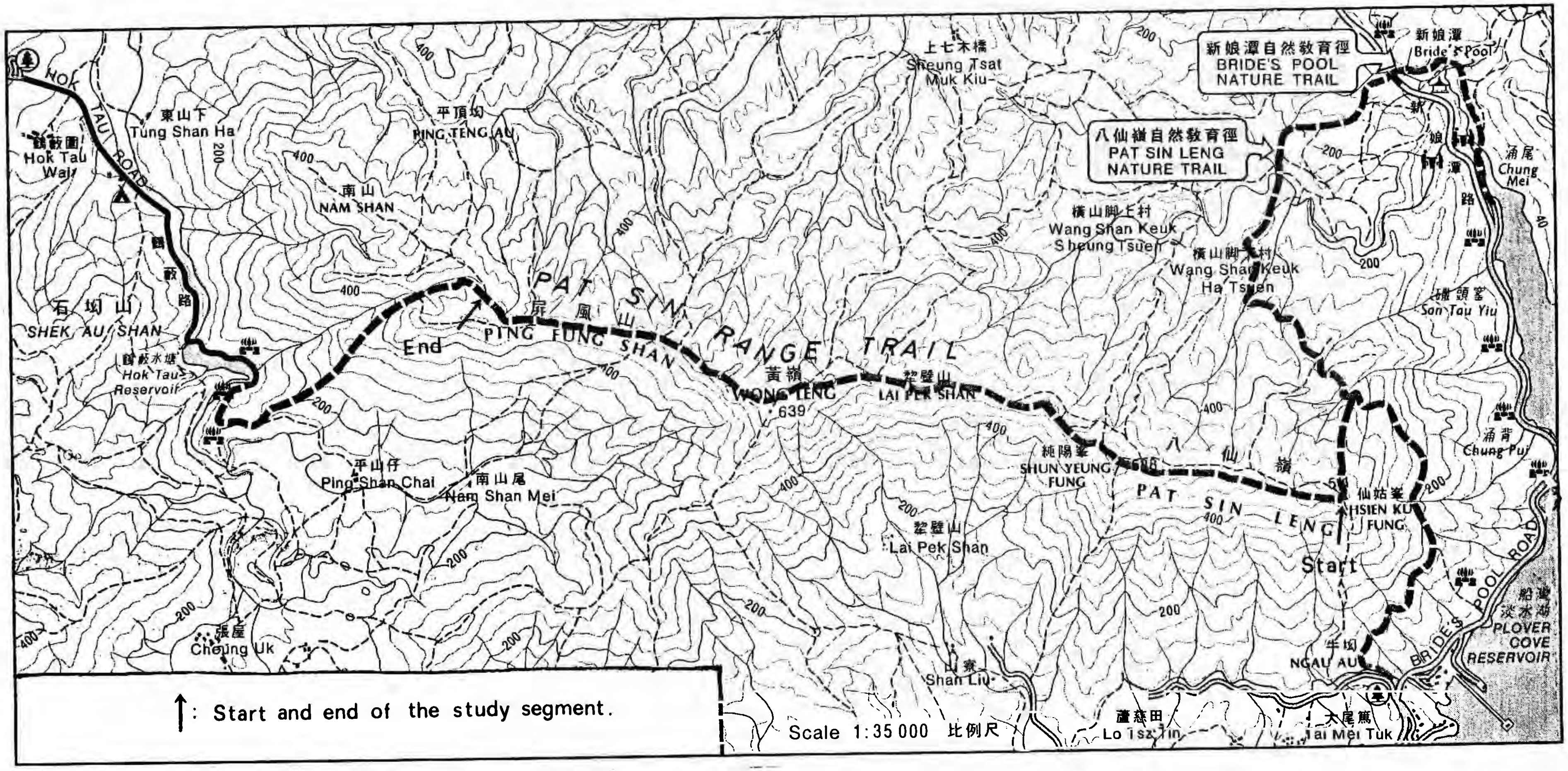
THE PAT SIN RANGE TRAIL

The PSR Trail commences in the eastern part of the park at a junction with the PSL Nature Trail. It steeply winds to the peak known as Hsien Ku Fung (511 m) of the Pat Sin Leng, and then links the ridges of Pat Sin Leng, Lai Pek Shan, Wong Leng and Ping Fung Shan, before ending at the Hok Tau Reservoir. The total length of the trail is about 8 km (Figure 3.8).

In the present study, only 6 km of the PSR Trail was investigated as there was evidence of intensive management works (mainly are rock steps) on the rest of the trail. The study trail segment starts at the peak of Hsien Ku Fung and ends at a trail junction at Ping Fung Shan (Figure 3.8).

The PSR Trail was a well-trodden footpath and a popular hiking route before designation of the Pat Sin Leng

Figure 3.8 Location of the Pat Sin Range Trail.



Refer to Figure 3.2 for legend explanations.

[Source : Survey & Mapping Office, 1991]

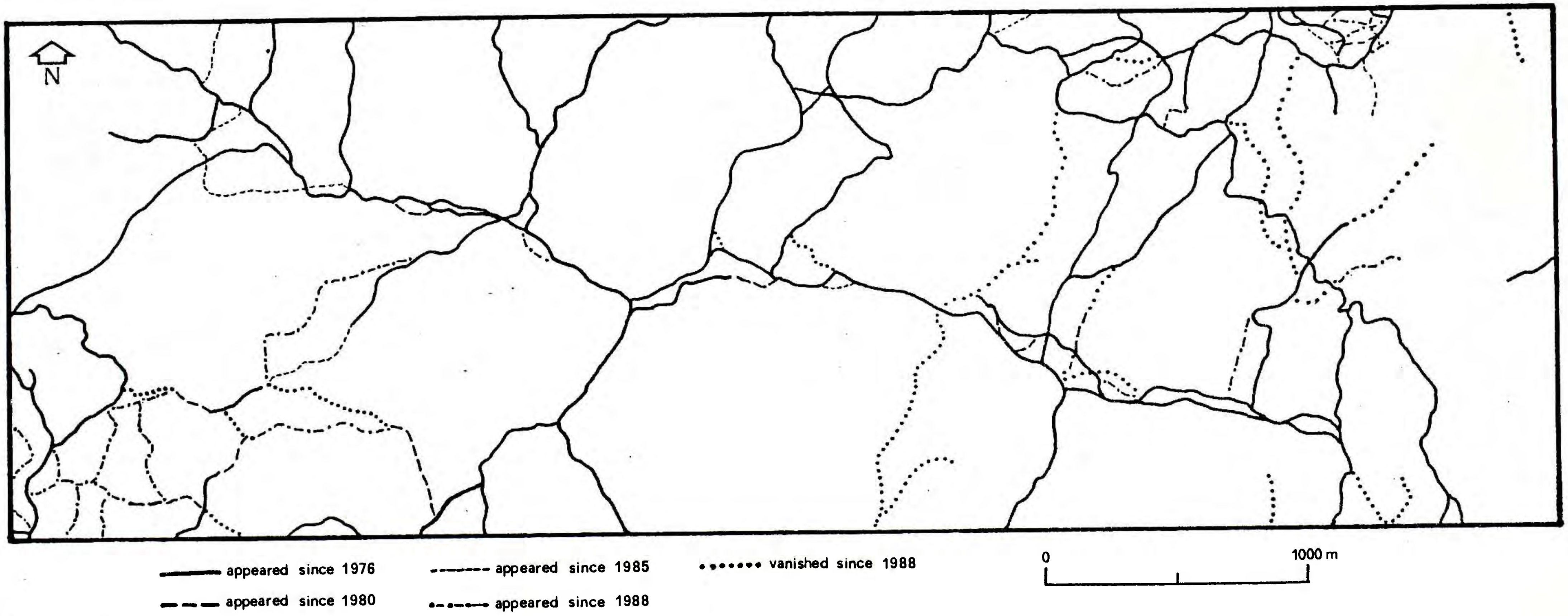
Country Park on the 18th of August, 1978 (Law, 1983). Very recently, it has become a part of the Wilson Trail which traverses the territory from south to north (South China Morning Post, 1992). There are also a number of trails and paths distributing or once existed along the PatSin Range (Figure 3.9).

Linking the ridges the PSR Trail provides a variety of topography, ranging from level passes to steep slopes (Figure 3.10). The majority of trail segments are facing either east or west. Such a variety in topography offers an excellent opportunity for investigating the influence of locational variables on the nature and severity of physical degradation.

The PSR Trail traverses the volcanic rocks at Pat Sin Leng and the sedimentary rocks west of Lai Pek Shan. This provides an example of bedrock control on trail degradation.

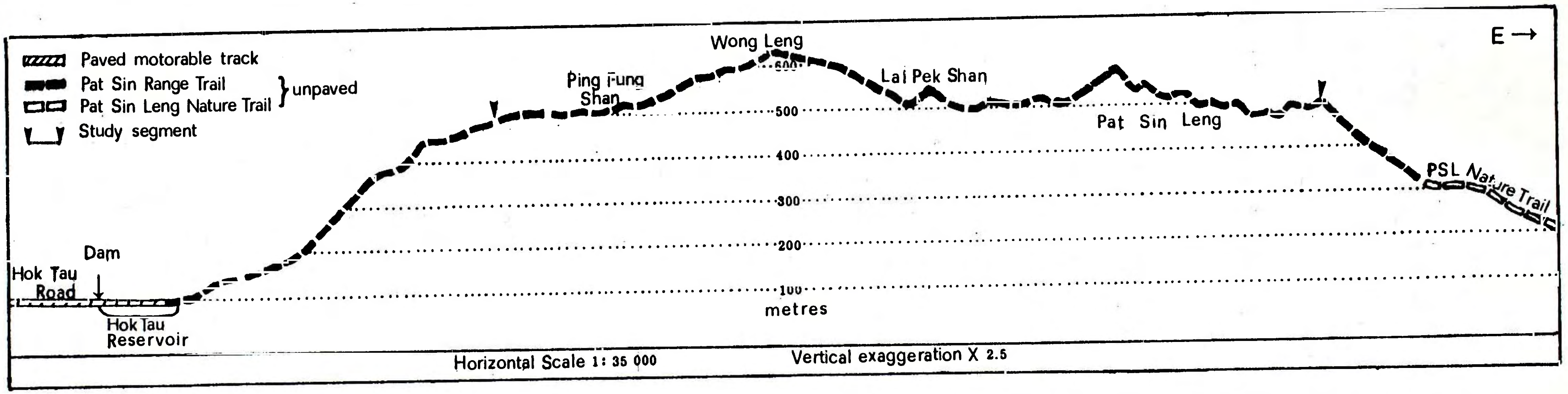
Owing to the relatively high elevations, most parts of the PSR Trail are underlain by skeletal lithosol whilst the occurrence of red-yellow podsols is restricted to the Pat Sin Leng with rocks of volcanic origin. No attempt has been made to study in detail the pedology of the Pat Sin Range Area, nor has there been an assessment of the erodibility of the soils. Based on the paucity of

Figure 3.9 Proliferation of trails and paths near the Pat Sin Range.



(Source: Lands & Survey Dept., 1976 & 1980; Survey Division, 1985; Survey & Mapping Office, 1987)

Figure 3.10 Cross-Section of the Pat Sin Range Trail.



[Source : Survey & Mapping Office, 1991] information, the present study explores only the physical properties of surface soil along the trail corridor. The PSR Trail is generally patronized from restricted entries: from Hok Tau to the West, Nam Chung and Luk Keng to the North, and Tai Mei Tuk and Bride's Pool to the East. However, hikers usually approach the trail from the eastern side and then walk westwards along the route, whilst few hikers may depart from the trail at intermediate trail junctions.

Most parts of the PSR Trail remain unsurfaced while steps are constructed at a very limited number of localities and have received little management input. Some basic information on local trail management practice was provided by Lay (1990) and Wong (1991). Park wardens would record all damaged facilities, including trail segments, during their routine patrol of the park. The follow-up maintenance work would then be accomplished by the Engineering Section of the same department under a limited budget. There is no monitoring and assessment system for trail management, nor are there any standard specifications for trail maintenance practices. The judgement of trail maintenance needs rest on whether a degraded trail segment is safe to the public, with little consideration on resource and aesthetic impacts, although all of these are cognate.

CHAPTER IV

RESEARCH METHODOLOGY

INTRODUCTION

The present study attempts to document the extent to which a popular hiking route has degraded at the time of study as well as to account for the variation in degradation along the trail as a function of environmental site conditions. Preliminary field trips were conducted during the summer of 1990. Most of the field measurements were conducted between December 1990 and July 1991, and laboratory analyses of soil physical properties was subsequently undertaken. Several supplementary field trips were also carried out to clarify some of the research findings.

RESEARCH DESIGN

Although it has long been recognized that studies with longitudinal (temporal) or experimental research designs often provide more precise information for the quantitative examination of the cause and process of degradation, the logistic constraints precluded these approaches in the present study. It was thus resolved to adopt a post-impact cross-sectional analysis.

By using standardized techniques, degradation-indicator variables were examined at systematically-selected sample sites along the trail, whereas locational and parent material variables were measured simultaneously at off-trail sites. As the study assumes that the off-trail sites represent pre-trail condition, variations in the degree of physical degradation at different sites could then be evaluated through a comparison of environmental site characteristics.

This approach to the study requires several assumptions. Firstly, the original site conditions of both the trail and the off-trail sites are assumed to be similar. This is a basic assumption for virtually all post-impact studies in which pre-disturbed condition are not known (Wall & Wright, 1977). The assumption implies that any difference in site conditions between a trail and its off-trail control can be attributed to the collective 'path effect' (Thrower, 1975) caused by micro-environmental change as well as by human interference (foot traffic in this case) on the trail.

Secondly, it was believed that the intensity of hiking use along the study trail was generally uniform and had reached a level at which variation in use-intensity was no longer a deterministic factor of trail degradation. This assumption was partly supported by the curvilinear use-impact relationship observed by most trail impact studies (Cole, 1987; Liddle, 1988 & 1989; Kuss et al., 1990). Moreover, the estimates by park wardens, outing groups, and the author all suggest that a few thousand hikers use this route annually and that many of them walk the full length of the trail.

The third assumption is that the difference in age within the length of the study trail causes also minor variations in the degree of degradation. This assumption is partly justified by the fact that the whole length of the study trail has been well-trodden for many years (Refer to Figure 3.9). Moreover, the curvilinear use-impact relationship as mentioned above is also well documented and most human impacts on trails occur during the initial construction and use.

Fourthly, there has been no extensive trail maintenance along the trail segment under study. Whilst there were few localities with discernible modifications, mainly rock-steps or drainage ditches, they were excluded from this study.

HYPOTHESES

The four hypotheses to be tested in the present study are:

(1) There are variations in the degree of physical degradation along the trail;

(2) There are variations in the measured environmental site

conditions along the trail;

(3) Variations in the degree of physical degradation amongst the sample sites are related to the differences in their inherent site characteristics;

(4) Owing to the physiographic variation, the relative importance of factors affecting trail degradation in the study trail is different from other studies.

SAMPLING SCHEME

The trail under study, commencing at Hsien Ku Fung to the east and ending at the Ping Fung Shan to the west, has a total length of 6 km. This length of trail was considered to be sufficient for characterizing the locational and soil variations in the study area.

Along the trail a systematic sampling scheme with an interval of 100 metres was adopted. The localities of sample sites were identified using a measuring tape. At each sample site, a cross-section was earmarked by spraying yellow paint on nearby boulders and by driving flagged metal pins into the soil at adjacent areas off the trail. The sites were then marked on a 1:5000 topographic map and a photograph was taken for reference.

Whenever a proposed sample locality was underlain by large rock outcrops where the trail tread was difficult to define, sample sites were moved forward in 10-meter units until an acceptable locality was found. Similarly, when encountering discernible human modifications, such as steps and drains, sample sites were moved forward in the same manner.

Fire scars were found at trailside areas near the Ping Fund Shan (between Sites 42 and 43). As the heat of a fire can alter soil properties, at least in the short term (DeBano & Rice, 1970; Durgin, 1985), sample sites within such zones were excluded from field measurements and sampling.

There were situations on some hills, mainly at Wong Leng and Ping Fung Shan, where the study trail branches into two well-defined segments: one leading up to the crest (Crest-Climbing branch hereafter), whilst the other passes by the sidehill (By-Pass branch hereafter), and they converge again on the other side. By observations, the majority of hikers were likely to prefer the Crest-Climbing branches to the By-Pass branches. Accordingly, these two types of branches may reflect different levels of use intensity. In order to compare the differences in site conditions as well as the degree of physical degradation, sample sites were set up on both branches.

A total of 58 sample sites were located along the study trail. Among them 27 sites were located on branch segments of which 13 belonged to Crest-Climbing branches and 14 to By-Pass branches. Figure 4.1 shows the location of sample sites along the trail.

VARIABLES INCLUDED IN THE STUDY

Degradation and site conditions of the trail were assessed using a number of field and laboratory based variables. The criteria for selecting these variables were:

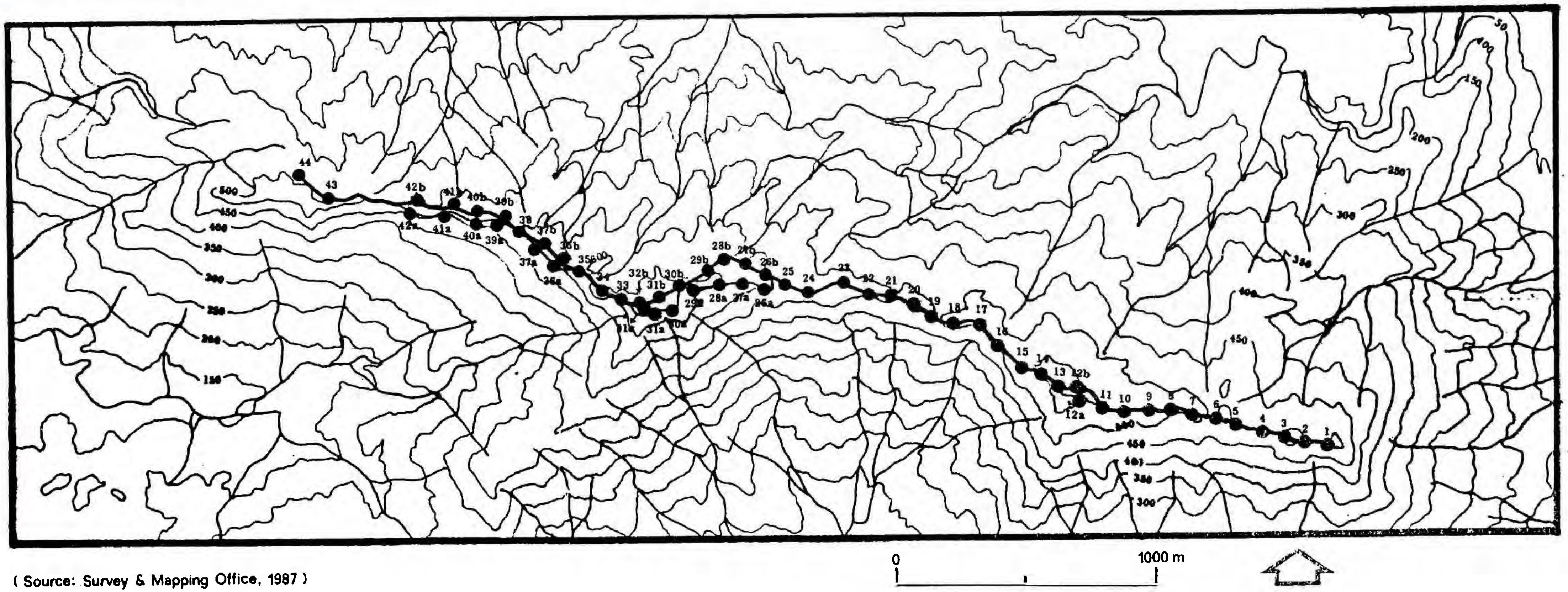
(1) they have been employed in previous studies so that comparisons can be made;

(2) they have been recommended by other researchers as significant indicators or factors of trail degradation;

(3) apparatus and instruments for field measurements should be both light to carry and quick to operate because of both the rough terrain of the study area and the labour constraint.

The variables finally selected are listed in Table 4.1. Most of the variables were determined by field measurements and laboratory work, whilst several variables were computed and derived from the raw data.

Figure 4.1 Location of the sample sites along the Pat Sin Range Trail



(Source: Survey & Mapping Office, 1987)

Table 4.1 The variables included in the present study.

Degradation-Indicator Variables	Site Condition Variables
-Penetration resistance on tread surface (MPRTL) [1]	-Penetration resistance at off-trail positions (MPRCT)
-Absolute change of penetration resistance (ABSCHG) [2]	-Trail slope (TLGD)
-Relative change of penetration resistance (PCTCHG)	-Terrain slope (SLGD)
-Tread Width (BW)	*-Trail-terrain slope difference (GDDF)*
-Incision depth of tread: Average incision depth (AID) Maximum incision depth (MID)	-Trail aspect (TLASP)
-Tread cross-sectional area (TCSA)	-Terrain aspect (SLASP)
-Form ratio (FMRATIO)	*-Trail-terrain angle (ASPDF)*
-Tread surface roughness (SDDP)	-Proportion of slope length to site in total length (LNPRP)
	-Trail position on slope (TLPOS)
	-Type of parent rock (ROCK)
-Percentage cover of: grass clumps (PTGRASS), plant litter (PTLITT), base rock (PTROCK), mineral soil (PTSOIL) and, gravel and stone (PTSTON) on tread surface	-Surface stoniness (STONIN)
	-Soil pH (PH)
	-Organic matter content (%OM)
-Number of multiple treads (NMLTTD)	-Textural anaylsis: percentage of sand (%SAND), silt (%SILT) and clay (%CLAY)
-Summary degradation score (DEG)	*-Soil textural class (TEXT)*
	-Index of textural uniformity (ITU)
	-Clay ratio (CLAYRAT)
	-Soil aggregate stability: as mean-weight diameter (ASMWD), as percentage of water-stable aggregates (>1mm) (AS1MM%)

1 Name in bracket is the abbreviation of the variable.
2 Variables in italic form are derived from raw information.

FIELD MEASUREMENTS

The field measurement and sampling of variables indicative of site and degradation condition were conducted in accordance with the design shown in Figure 4.2.

Degradation-Indicator Variables

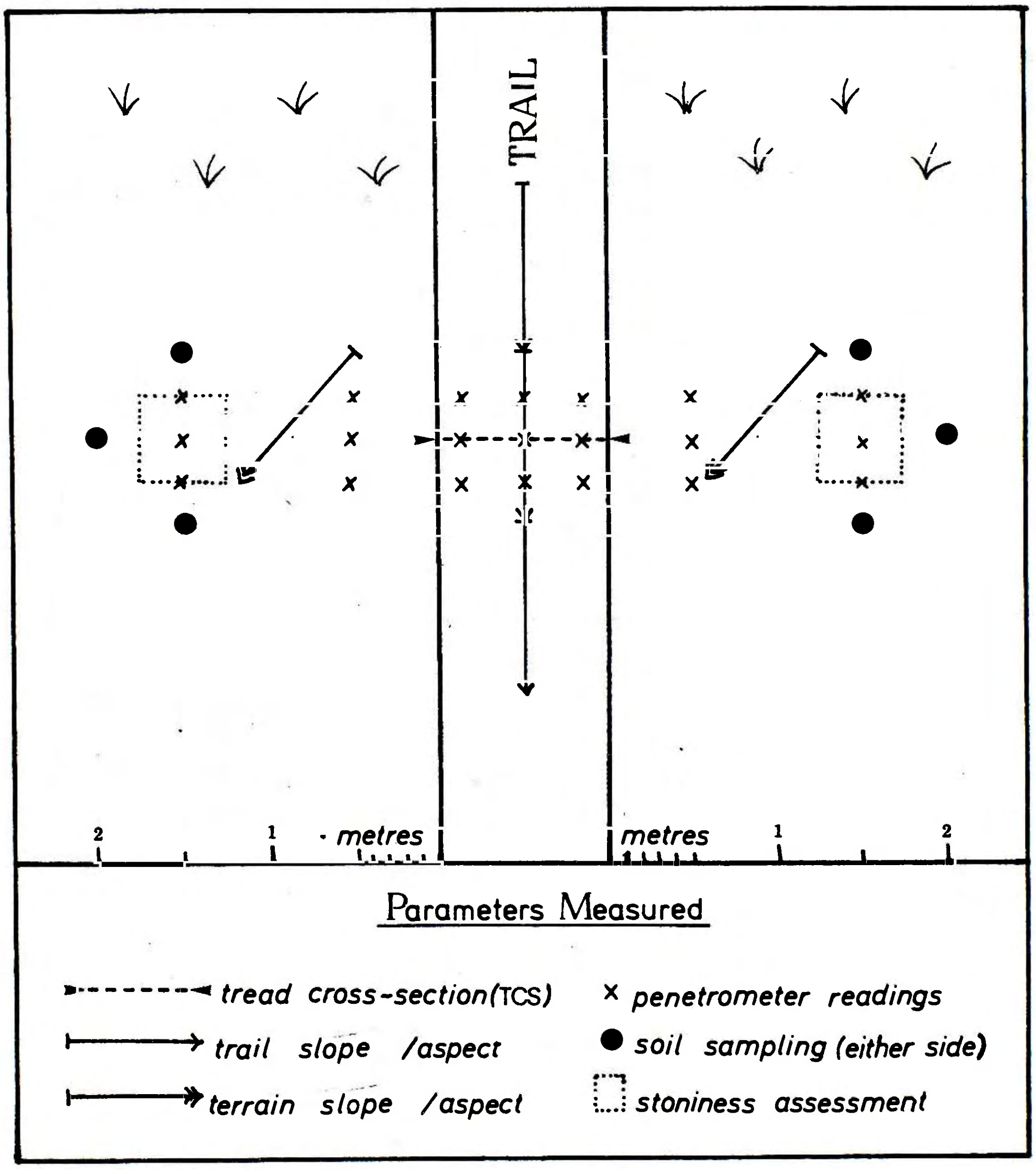
Penetration resistance

Compaction of trail tread was assessed by the change in penetration resistance amongst different positions across the trail tread. Penetration resistance readings were taken on 7 different positions, with the use of a pocket penetrometer (Control, Model 40-T163). The values were originally read as MPa and were converted and reported as the commonly-used unit kg/cm^2 (1 MPa = 10.2 kg/cm^2).

There are several limitations of the penetrability measurements which should be kept in mind. As the study trail passes on terrain with thin and stony parent material, the existence of gravels on and off trail may interfere with the penetration resistance readings. However, after experimental trials of the two commonly-measured compaction indicators, the penetrometer technique seemed to outweigh that of bulk density, because it was less bulky in operation on rough terrain and created less disturbance on and along the treads.

Figure 4.2

Sample design of field measurements at the sample sites.



The presence of bedrock outcrops prohibited the penetrometer measurement at several sample sites. This resulted in varied sample sizes at different positions within a site as well as amongst different sites. Moreover, when the penetration resistance reading exceeded the instrument's maximum at a measuring point where no impediment was found, the maximum value of 1 MPa was recorded at that measuring point. Hence, the results may to a certain extent underestimate the degree and the variation of compaction.

On the trail tread, measurements were taken at 3 positions: the centre, southern edge and northern edge of the tread surface. Three readings were recorded for each position (Refer to Figure 4.2).

Tread cross-section (TCS)

One useful measurement in trail morphology is the trail cross-section (or trail transect, trail profile)which is indicative of the degree of physical degradation. This measurement provides information on the width, incision depth and cross-sectional area loss of a trail. This technique was developed by Ketchledge & Leonard (1970) and Leonard & Whitney (1977). The technique, with minor variations, has been employed by Helgath (1975), Tinsley & Fish (1985), Summer (1980 &

1986), Burde & Renfro (1986) and Cole (1983a & 1991) (Table 4.2).

Despite its usefulness, trail cross-section is only a surrogate measure of the long-term erosion process and there are uncertainties in determining the original surface of the landform before the existence of the trail (Cole, 1992; Liddle, 1992).

Recognizing that a trail is an indispensable facility in country parks, the primary concern in the present study is the effect of the physical degradation

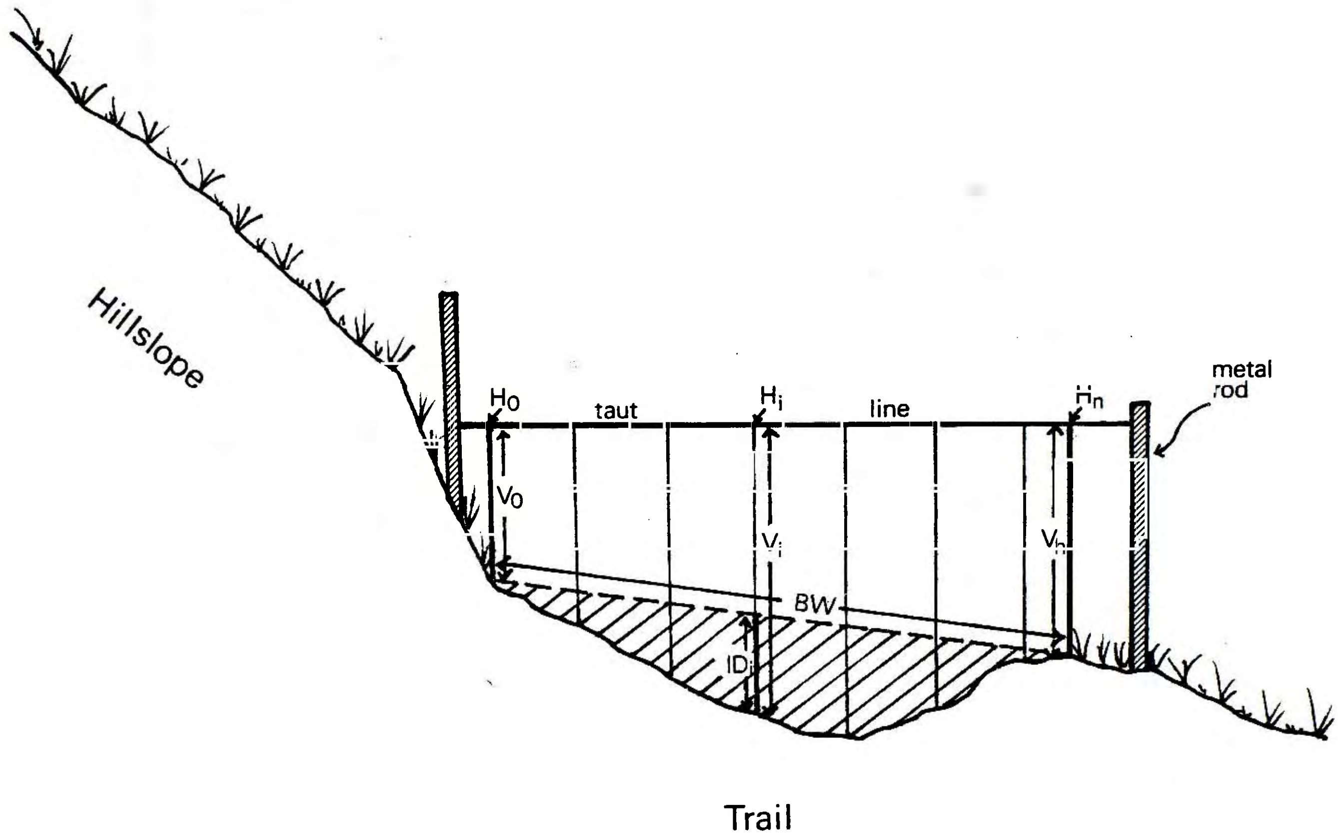
Table 4.2 Design of trail cross-section measurements in some selected trail studies.

Researcher	Environment	User Type	Sampling Scheme	No. of Samples	Interval of Vertical Measurements
Helgath (1975)	subalpine	human+ horse	purposive	70	10cm
Summer (1980 & 86)	alpine	horse	stratified	30	3-6cm
Tinsley & Fish(1985)	semi-arid	human+ horse	stratified	39	15.24cm
Burde & Renfro(1986)	temperate	human	systematic (intv:500m)	221	3cm
Cole (1983a & 91)	subalpine	human+ horse	systematic (intv:1600m)	33	6cm

of trails on their functioning and aesthetic quality. Hence, this study attempted to estimate only the recent soil loss by measuring the cross-sectional area below the tread surface (named Tread Cross-Sectional Area, TCSA). No attempt was made to estimate the total soil loss by reconstructing the original landform, as this requires a long use and management history.

Figure 4.3 illustrates the details of the TCS measurement in the present study. Two metal rods and 2 fibreglass measuring tapes were employed in this work. One of the measuring tapes was attached with two spirit levels and extended horizontally between the two rods at each side. The other was suspended with a plumb bob and used for taking vertical measurements to the nearest 1 mm, commencing from the northern or eastern edge of tread, along the horizontal line at an interval of 5 cm (See also Plate 4.1). The tread edge boundary was noted as the point of contact between the exposed soil or bedrock and the trailside vegetation. To give the final results, the vertical readings obtained were corrected for the length of the plumb bob and the raw data were analyzed using the formula listed in Figure 4.3. Whenever multiple treads existed, each of the treads was measured individually and then added up to provide a total value.

Figure 4.3
Field measurement of the tread cross-section.



$$TCSA = \left\{ \sum_{i=1}^{n} [(V_i + V_{i-1})(H_i - H_{i-1})/2] \right\} - [(V_0 + V_n)(H_n - H_0)/2]$$

$$ID_i = V_i - H_0 - [(H_i - H_0)(V_n - V_0)/(H_n - H_0)]$$

$$BW = [(H_n - H_0)^2 + (V_n - V_0)^2]^{\frac{1}{2}}$$

TCSA: Tread Cross-Sectional Area (shaded area) (cm^2)
$H_0 \rightarrow H_n$: Horizontal Distance Readings (cm)
$V_0 \rightarrow V_n$: Vertical Distance Readings (cm)
ID_i: Incision Depth of Tread (cm)
BW: Bare Width of Tread (cm)

Plate 4.1 Measuring tread cross-section in field.

Tread Width (BW)

The determination of bare width is less subjective than those measures of total disturbed or trampled vegetation as indicator of trail width (Leonard & Whitney, 1977; More, 1980, Prouder, 1985). For this reason, only bare width of tread (refer to as tread width hereafter) was determined through the TCS measurements. Bare width is defined as the trail tread devoid of vegetation (Dale & Weaver, 1974; Lance et al., 1989).

Incision depth of tread

The vertical depth into which the tread surface is incised is defined as the incision depth. It was also determined by the cross-section measurement of trail tread (Figure 4.3). The results were reported as average incision depth (AID) and maximum incision depth (MID).

Tread cross-sectional area (TCSA)

The cross-sectional area gives a surrogate estimate of soil loss from trail tread as there are no records on the actual trail erosion in the study area. The TCSA value was computed from the sum of the tetragonal areas minus the area of trapezium between the horizontal line and the tread line (BW) (Figure 4.3).

Other morphological variables

Multiple treading, the existence of multiple parallel treads (or secondary paths) alongside the main tread, is clear evidence of degradation on trail. It also has significant implications on aesthetic quality and prospective degradation. In this study, the number of discernible multiple treads (NMLTTD) at each sample site was recorded.

Surface roughness refers to the variation in the surface elevation across a field. It was included for its probable influences on erosion process (Morgan, 1986) as well as on user behaviour. In this study, tread surface roughness (SDDP) was expressed as by the standard deviation of incision depth measurements across the trail tread.

Tread form-ratio (FMRATIO), defined as the ratio of bare width (BW) to average incision depth (AID), is a variable originally derived from the measurement of river channel form (Richards, 1990). It was used as an index of shape of tread surface.

Tread surface material

There were five types of surface material on the treads, namely, solitary grass clumps, plant litter, base rock, mineral soil, and stone/gravel. For each of the vertical measurements in the TCS determination, the type of surface material onto which the plumb bob made contact was recorded. The frequency of occurrence of each type of surface material was reported as percentage cover (Leonard & Whitney, 1977).

In order to verify the reliability of tread cross-section measurements, six sample sites (10% of total) were randomly selected, and 3 replicate measurements were made at each site. Variations in TCS measurements at a sample site were compared statistically to those amongst different sites (Table 4.3). The results suggest that the variability of measurement amongst different sample sites was generally greater than at a sample site. Recognizing this fairly high reliability and long time required for each measurement, it was resolved to make one set of cross-section measurements for each sample site where the morphology of the trail tread could be sufficiently characterized.

Site Condition Variables

Only penetrability, locational variables, and parent material were examined in the present study. Locational

Table 4.3 Variations in tread cross-section measurements amongst different sample sites as compared to the variations within individual sites.

Variable	Chi-square value [1]	Signif.	N
Bare Width (BW)	13.91	0.02*	18
Average Incision Depth (AID)	11.85	0.04*	18
Maximum Incision Depth (MID)	7.41	0.19	18
Cross-Sectional Area (TCSA)	10.45	0.06[a]	18
Tread Surface Roughness (SDDP)	6.08	0.30	18
Form Ratio (FMRATIO)	12.93	0.03*	18
% Grass on Tread (PTGRASS)	12.65	0.03*	18
% Plant Litter on Tread (PTLITT)	12.22	0.03*	18
% Base Rock on Tread (PTROCK)	5.07	0.41	18
% Mineral Soil on Tread (PTSOIL)	11.65	0.04*	18
% Gravel/Stone on Tread (PTSTON)	14.75	0.01*	18

[1] Kruskal-Wallis 1-Way ANOVA Test (a - p<0.1; * - p<0.05).

variables were measured on trail, whilst penetration resistance and parent material were measured or sampled at off-trail sites to reflect the inherent condition (Refer to Figure 4.2).

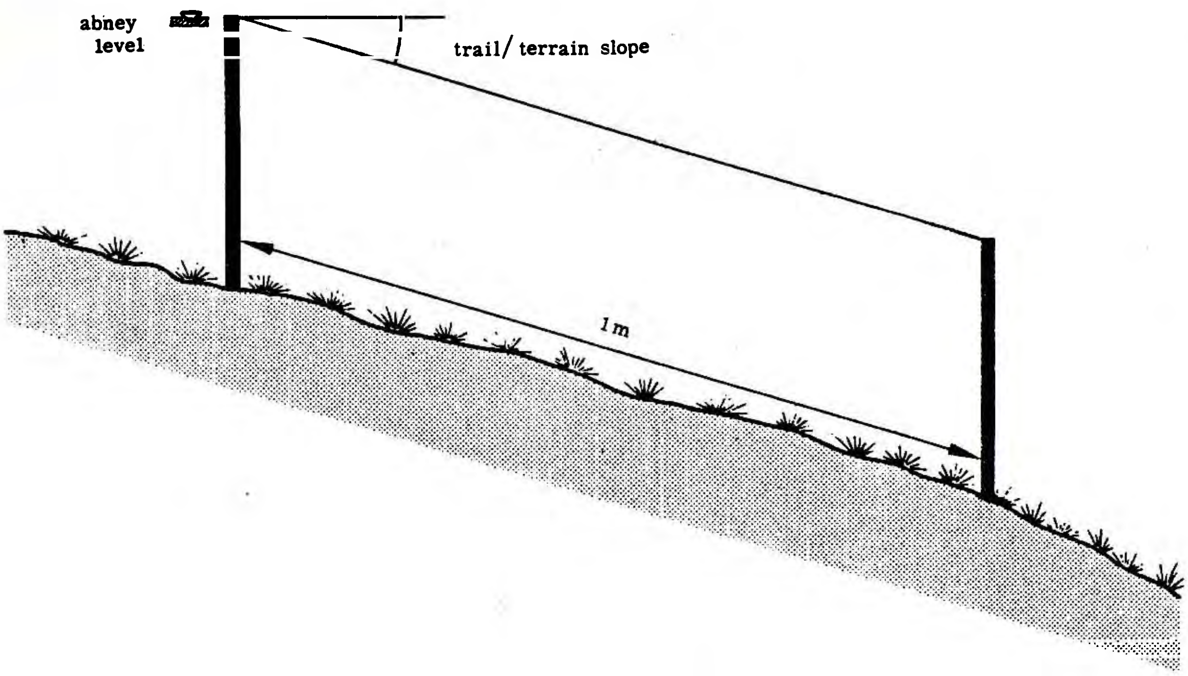
Penetration resistance

A series of penetrometer measurements were taken at 4 off-trail positions which are 0.5 metre and 1.5 metres away from both edges of the trail in addition to the trail tread measures (Refer to Figure 4.2). As discussed in the next chapter, the degree of compaction was assessed by absolute (ABSCHG) and relative (PCTCHG) change in penetration resistance between trail positions and off-trail positions.

Slope and aspect

The slopes of both the trail and terrain (maximum slope) were measured using an abney level and small ranging poles. The layout of this measurement is illustrated in Figure 4.4. The commonly-used measuring length of 1 m was used (Cox, 1990). A total of 3 measurements (1 m interval) were taken for trail slope and 2 were taken for terrain slope. The aspects of both the trail and the terrain (downhill direction) were determined by Brunton compass.

Figure 4.4 Field measurement of trail and terrain slope.



Trail position on slope

Whenever sample sites were located on trails which directly ascended or descended a slope, the slope length from the crest to the site, and the total slope length were measured. The proportion of site slope length to total length (LNPRP) was then computed. A site with a LNPRP value less than 0.5 was defined as a 'direct-ascent' trail (perpendicular to the contours) on the upper slope position. Similarly, sites with LNPRP values greater than 0.5 were classified as direct-ascent trails on the lower slope position.

The above classification do not apply to those sites which directly ascend/descend but were located on interfluves (catchment boundaries), as field observation suggested that these sites differed from the above two trail positions in terms of their degradation condition.

Five types of trail position modified from Huxley (1970) were finally classified in this study:

(1) direct-ascent trail on upper slope positions (DA-Upper Slope);
(2) direct-ascent trail on lower slope positions (DA-Lower Slope);
(3) direct-ascent on interfluve (DA-Interfluve);
(4) oblique or contour trail passing at sidehill (OB-Sidehill);
(5) level ground such as right at crest or at valley floor (LV-Crest/Floor).

Parent rock and stoniness

The type of parent rock underlying the sample sites was determined with the use of the most recently published 1:20000 geology map (Geotechnical Control Office, 1991). It was verified by an examination of rock outcrops where they occurred.

The off-trail stoniness was determined in accordance with the method described by McRae (1988), involving the use of a 0.5m x 0.5m quadrat. Two estimates were made for each site and averaged as a stoniness class (Table 4.4).

Soil sampling

At each sample site, three core soil samples (15 cm deep, 6 cm in diameter) were taken 1.5 and 2 metres away from the tread edge. This was done on only one side of the trail, the side being randomly determined.

Efforts were made to collect soil samples from the tread surface, but the hardness of the tread and the great disturbance incurred in obtaining a sample led to the abandonment of the sampling. Thus, a comparison of soil properties between the trail and off-trail sites cannot be made.

Table 4.4 The stoniness class.

Class	Stone coverage
Stoneless	< 1%
Very slightly stony	1-5%
Slightly stony	6-15%
Moderately stony	16-35%
Very stony	36-70%
Extremely stony	>70%

(Source: McRae, 1988)

LABORATORY ANALYSIS

The selection of soil properties for laboratory analysis was made with respect to their relevance to the erodibility of soil, which is the soil's susceptibility to detachment and transport by the agents of erosion (Morgan, 1986). The parameters should also be consistent and do not have pronounced diurnal variations or similar short-term changes.

Soil properties, such as infiltration capacity and soil moisture, were excluded from field measurement since they could be subsumed under soil texture and organic matter content. There is also difficulty in handling such measurements at many sites within a limited time frame.

Soil samples were air-dried and bulked (Peterson & Calvin, 1965) then passed through a 2-mm sieve before analysis.

Soil pH (soil to water ratio 1:2.5) was determined using a soil electrode (Model 5992-62, Cole & Parmer). Organic matter content was estimated using the loss on ignition method (Allen et al., 1974).

Soil texture was determined using hydrometers (Allen et al., 1974). Results were expressed as percentages of sand, silt and clay, the clay ratio (sum of percent sand and silt divided by percent clay), and the texture class (USDA Textural Scheme). Another index, the Index of Textural Uniformity (ITU), was derived from the percentage of the greatest fraction divided by that of the smallest fraction. Originated from the coefficient of uniformity (Craig, 1987), the ITU index can indicate how uniform the surface soil is.

Aggregate stability, one of the main factors controlling topsoil hydrology, crustability and erodibility (De Ploey & Poesen, 1985), was determined using the techniques described by Kemper (1965) and Grieve (1978). Fifty grams of air-dried 2 mm sample were first misted using a sprayer and then wet-sieved in water for 5 minutes. Aggregates and sand retained on the 1 mm and 0.5 mm sieves were collected, oven-dried and weighed. They were then subject to a second wet-sieving in 0.1 Mole sodium hydroxide, which disintegrates the aggregates. Sand retained on the sieves was then oven-dried and weighed as a correction factor to determine the amount of water-stable aggregates in the soil.

Soil aggregation was expressed as the percentage of water-stable aggregates (> 1mm). It was also expressed as the Mean-Weight Diameter (MWD) value, which is the sum of the percentage of soil retained on each sieve multiplied by the mean particle diameter of the adjacent sieves (in this study

1.105 & 0.5125 mm) (Chaney & Swift, 1984). The calculation is:

MWD = (% sample on sieve X mean intersieve size)

These two aggregate stability expressions, together with the clay ratio, are common indexes of soil erodibility (Lal, 1988), the inclusion of which permits comparisons of their performance in explaining trail degradation.

DATA MANIPULATION AND ANALYSIS

Software Lotus 123 (version 3.1) was employed for storing all the collected data which were then extracted for statistical analysis using the SPSS-PC package (version 3.1).

In addition to reporting the results of individual degradation-indicator variables, a summary 'Degradation Score', using z-scores was derived (Marion, 1991). Z-scores for each of the four trail morphology variables: BW, MID, TCSA and NMLTTD were first calculated. They were then summed as an integrated degradation score:

Degradation Score (DEG) = ZBW + ZMID + ZTCSA + ZNMLTTD

(ZBW, ZMID & ZTCSA & ZNMLTTD are z-scores of BW, MID, TCSA and NMLTTD respectively)

All data were subject to a test of normality using the Kolmogorov-Smirnov One-Sample Test (Siegel, 1988). Both parametric and non-parametric statistics were then employed for the analyses of normally-distributed and skewed data respectively. A significance level of 0.05 was used as a threshold for all statistical tests.

CHAPTER V

SITE AND DEGRADATION CONDITION OF PAT SIN RANGE TRAIL

INTRODUCTION

In this chapter trail site condition, as shown by locational and parent material variables, and tread surface material on the study trail will be reported, followed by an analysis of the degree of physical degradation along the trail. Individual degradation-indicator variables will be assessed and the overall condition will be evaluated using a summary rating.

SITE CONDITION OF THE TRAIL

As described in Chapter III & IV, the PSR Trail under study extends a length of 6 km, including branching segments at several localities. A total of 58 sample sites along the trail were located and investigated. These sites represent a wide variety of site situation as indicated by their locational and parent material characteristics.

Parent Material

Information on parent material was obtained from field measurements at off-trail sites where undisturbed conditions were assumed. Table 5.1 and Figure 5.1 illustrate the distribution of sample sites on different parent rocks and soil texture classes. There were 23 sites located on rocks of volcanic origin where clay loam is the resulting predominant soil textural class. However, in the sedimentary rock environments, loam and sandy loam replace clay loam as the dominant soil textural classes (77.1% of sample sites). This indicates a marked decrease in the clay content of the sedimentary-derived soil.

With respect to surface stoniness, 62% of sites were described as 'very stony' (22 sites) and 'extremely very stony' (14 sites). This reflects the restricted soil profile development of the residual hill soils. Surface

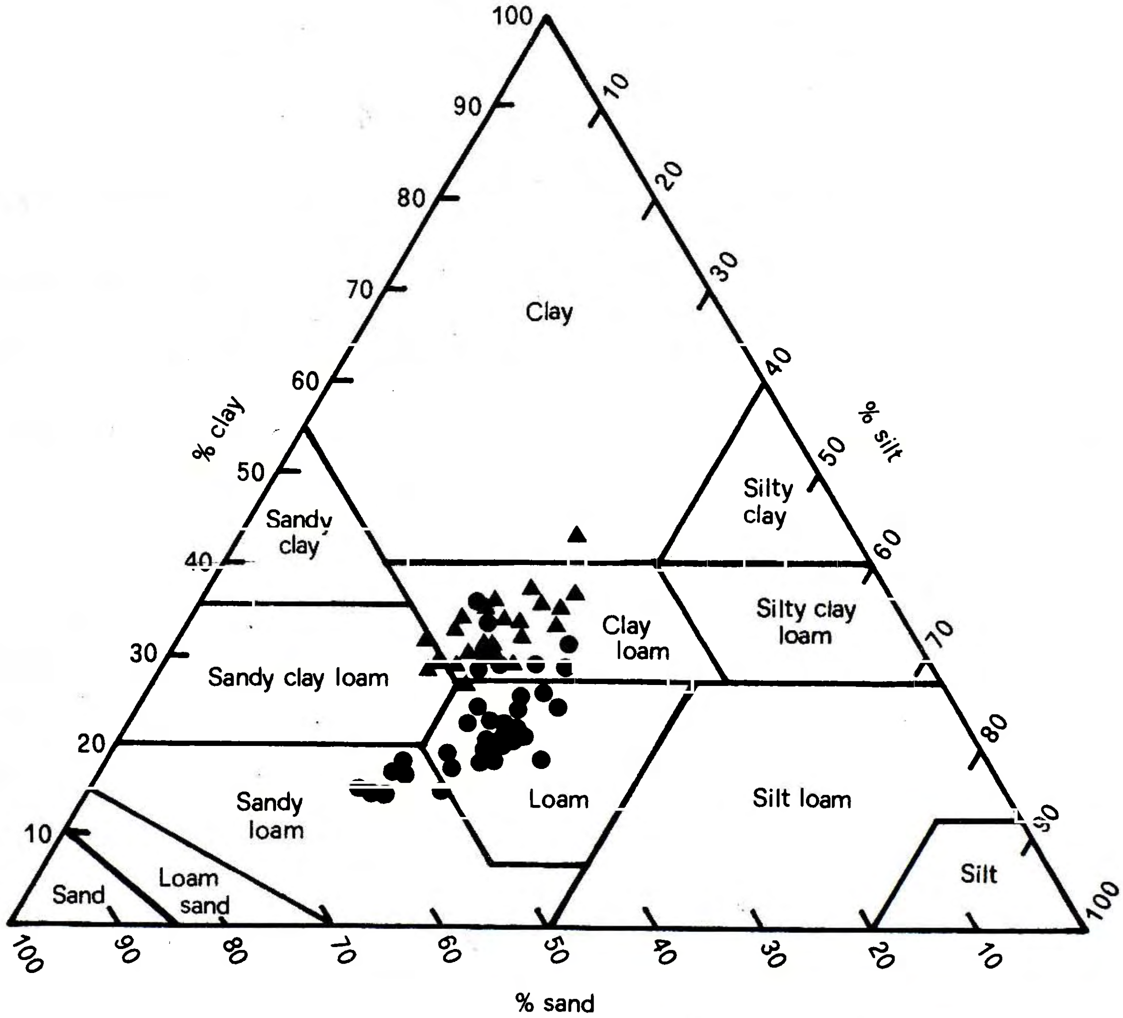
Table 5.1 The distribution of sample sites on different parent rocks and soil textural classes.

Rock Type	Soil Texture Class					No. of Sites
	sandy loam	loam	sandy clay loam	clay loam	clay	
Volcanic	0	1	3	18	1	23
Sedimentary	7	20	0	8	0	35
No. of Sites	7	21	3	26	1	58

Chi-Sq. Test: $p<0.01$ (df=4)

Figure 5.1

Textural-class* diagram of sample sites with respect to rock type.



▲ Volcanic rock

● Sedimentary rock

* USDA Scheme

stoniness was also related to the difference in parent rock (Table 5.2). About 65% of the sample sites on volcanic rock along the eastern part of the trail were classified as 'moderately stony' or less, whilst 80% of sites on sedimentary rocks were classified as 'very stony' to 'extremely stony'.

These results indicate that the soils forming on the sedimentary rocks have higher percentages of coarse soil particles and are more stony, whilst the volcanic rocks generated finer soil surfaces. Such variations could be explained by the difference in soil maturity between the two rocks. Besides, the inherently stony sedimentary rock environments may also imply a stony trail as well.

Table 5.2 The distribution of sample sites on different stoniness classes with respect to rock type.

Rock Type	Stoniness Class [1]						Mean Stonin. Value	No. of Sites
	STL	VSS	SS	MS	VS	ES		
Volcanic	3	4	3	5	7	1	3.52 (0.32)[2]	23
Sedimentary	0	1	3	3	15	13	5.03** (0.18)	35
No. of Sites	3	5	6	8	22	14	4.43	58

[1] Stoniness class: STL-Stoneless; VSS-Very slightly stony; SS-Slightly stony; MS-Moderately stony; VS-Very stony; ES-Extremely stony

[2] Standard error

** Mann-Whitney test: $p<0.01$

Most of the other soil physical properties, except for soil reaction pH, were significantly different between the two parent rocks (Table 5.3). In the volcanic-derived soils, clay fraction, organic matter content and aggregate stability were higher. In contrast, the sedimentary-derived soils is associated with greater fractions of sand and silt, and have a higher clay ratio and Index of Texture Uniformity (ITU). Many of the soil properties were also closely interrelated (Table 5.4). For example, the silt and clay fractions, and organic matter content are closely related to aggregate stability.

Table 5.3 Comparison of soil physical properties between the two parent rocks in the study area.

Soil Variable	All Sites (n=58) Mean	S.E.	Volcanic (n=23) Mean	S.E.	Sedimentary (n=35) Mean	S.E.	t-value[1]
Sand%	42.70	0.94	38.88	1.17	45.21	1.18	-3.82**
Silt%	31.16	0.53	28.99	0.63	32.59	0.68	-3.87**
Clay%	26.14	0.89	32.13	0.78	22.20	0.89	8.37**
Clay ratio	0.77	0.03	0.65	0.03	0.86	0.05	-3.85**
ITU[2]	1.92	0.10	1.44	0.06	2.23	0.14	-5.18**
pH	4.10	0.02	4.07	0.02	4.13	0.02	-1.86ns
OM%	0.96	0.05	1.18	0.04	0.82	0.06	4.72**
AS-MWD	96.16	1.12	100.69	0.94	93.18	1.56	4.12**
AS(>1mm)%	59.35	1.57	68.60	1.34	53.28	1.83	6.75**

[1] ns: not significant; **: $p<0.01$ (positive and negative t-values indicate soil parameters have greater mean values on volcanic and sedimentary rocks respectively.)
[2] Index of textural uniformity

Table 5.4 Correlation coefficients of the soil physical properties.

Soil Variable	Sand%	Silt%	Clay%	Clay Ratio	ITU [1]	pH	OM%	AS-MWD
Silt%	-0.37**							
Clay%	-0.83**	-0.21						
Clay ratio	0.98**	-0.39**	-0.80**					
ITU	0.90**	-0.18	-0.84**	0.94**				
pH	0.16	0.10	-0.22	0.18	0.13			
OM%	-0.56**	-0.08	0.63**	-0.56**	-0.59**	-0.07		
AS-MWD	0.02	-0.28*	0.14	-0.01	-0.11	0.05	0.51**	
AS(>1mm)%	-0.28*	-0.34*	0.49**	-0.30*	-0.42**	-0.19	0.66**	0.74**

Pearson correlation coefficient -- *: $p<0.05$; **: $p<0.01$ ($n=58$)
[1] Index of Textural uniformity.

From these results it can be hypothesized that soils developed on volcanic rocks may be less erodible due to their higher organic matter content and aggregate stability. The actual relationship between such properties and trail degradation will be explored in the next chapter.

Topography

The summary statistics of several topographic variables is shown as Table 5.5. The data of all these variables are normally distributed.

As mentioned in Chapter III, the study trail follows the main East-West orientation of the ridges of the Pat Sin

Table 5.5 Summary statistics of topographic characteristics of the study trail.

Variable	N	Mean	Median	S.E.	Range	Skewness[1] of Data
Elevation (m)	58	544.5	530.0	5.6	484.0-637.0	ns
Trail-terrain angle (deg)	39	52.7	54.0	5.0	0.0-90.0	ns
Trail slope (deg)	58	10.3	8.6	1.0	0.3-33.6	ns
Terrain slope(deg)	44	19.9	17.5	1.2	6.3-38.0	ns
Slope difference (deg)	44	10.0	6.8	1.4	1.6-31.8	ns

[1]Kolmogorov-Smirnov Goodness-of-Fit Test (ns: not significant)

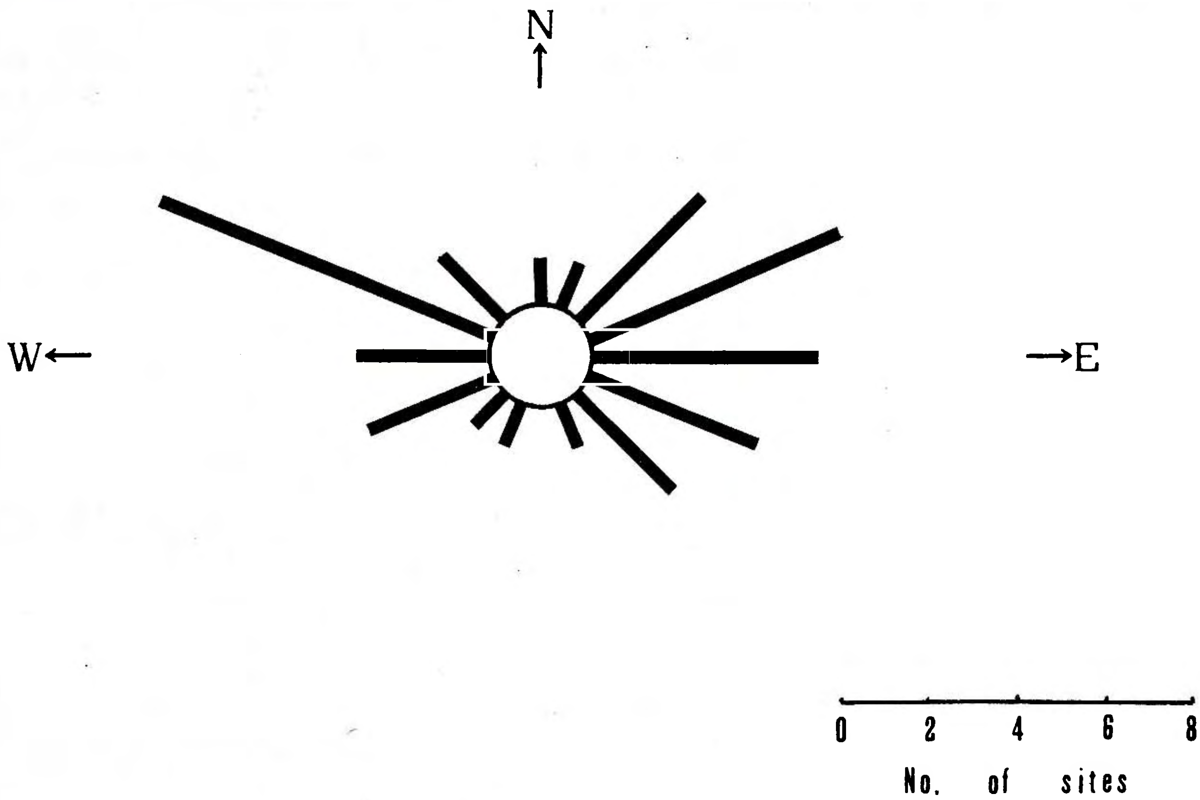
Range. Owing to the predominance in terrain direction, the trail aspect measured at the sample sites exhibited a bimodal distribution (Figure 5.2; Table 5.6a). Most of the sites faced either eastward or westward. Nevertheless, the pattern of terrain aspect was less conspicuous (Figure 5.2; Table 5.6a). At a number of sites, the aspect of the surrounding terrain could not be determined due to the complexity of the topography involved. There was also no difference in the aspects of either the trail or the terrain between the two parent rocks.

The trail-terrain angle, also known as the environmental angle (Bratton et al., 1979), indicates the

Figure 5.2

Rose diagram showing the distribution of sample sites on various aspects.

[a] Trail Aspect



[b] Terrain Aspect

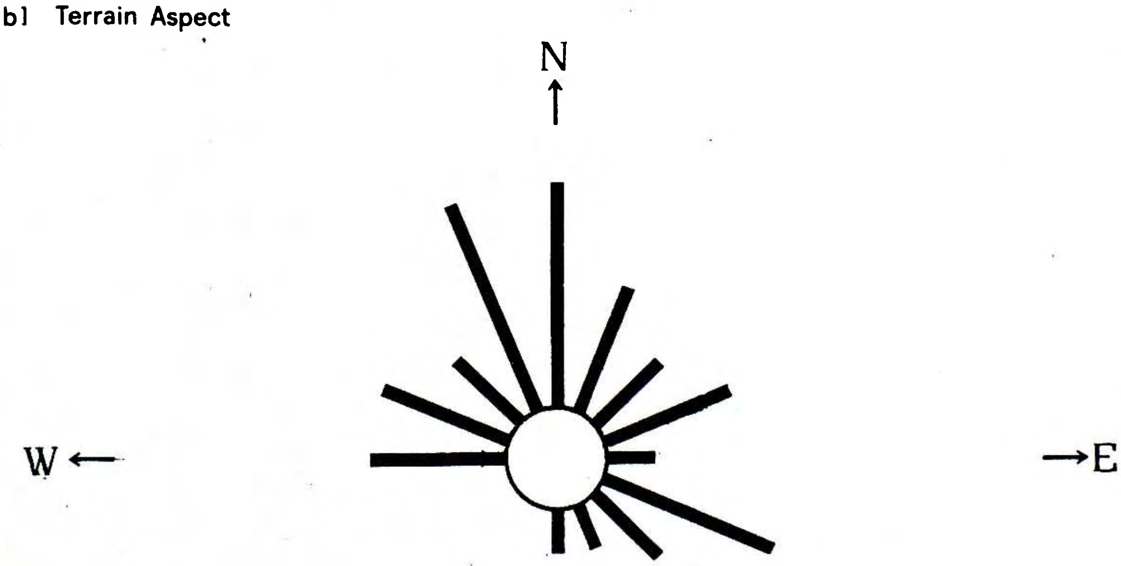


Table 5.6 Trail aspect, terrain aspect and their angle of the sample sites.

(a) Trail and terrain aspects

Compass Bearing	Direction	No. of Sites		% of Total Sites	
		Trail	Terrain	Trail	Terrain
315–45^0	NW - NE	4	17	6.9	43.6
45–135^0	NE - SE	27	10	46.6	25.6
135–225^0	SE - SW	5	4	8.6	10.3
225–315^0	SW - NW	22	8	37.9	20.5
Total No. of Sites		58	39	100	100

(b) Trail-terrain angle

Angle (degree)	No. of Sites	% of Total Sites
0 - 15	6	10.3
15 - 30	3	5.2
30 - 45	6	10.3
45 - 60	6	10.3
60 - 75	5	8.7
75 - 90	13	22.4
Not determined	19	32.8
Total	58	100

extent to which the aspect of the trail deviates from that of its surrounding terrain. A zero value indicates that the trail exactly follows the maximum slope of the terrain, whilst the maximum trail-terrain angle value of 90^0 indicates a situation where the trail cuts across the sideslope.

The average trail-terrain angle of the 39 sample sites was 52.7^0 (Table 5.6b). Amongst these sites, 6 were less than 15^0 (all were virtually zero). Four of these sites were situated on the hillslopes of Pat Sin Leng and the remaining two in the vicinity of Wong Leng. The distribution of sample sites on different classes of trail-terrain angle is shown in Table 5.6b.

The study trail links most of the ridge crests along the Range, resulting in steep trail slopes. The mean slope of the study trail was 10.3^0 (18.2%), with a range from 0.3^0 (0.5%) to 33.6^0 (66.4%) (Table 5.5). The trail segments at Pat Sin Leng were generally steeper as many segments provided access to the crests by the shortest distance. Along the western part, trail slopes were less steep and some segments even passed by the crests at which some branching segments were found.

Trail slope has been found to be associated with the slope of the underlying terrain (Garland et al., 1985). In the present study, the spatial pattern of terrain slope was found to be similar to that of trail slope. Terrain slopes at Pat Sin Leng are as steep as 38^0 (78.1%) whilst those at Wong Leng and Ping Fung Shan were much gentler. However, the correlation coefficient between trail and terrain slope was significant only at $p<0.1$ level (Figure 5.3).

Trail slope is also presented categorically to enable a comparison of rock types (Table 5.7). Increasing intervals of slope were used to reflect the nonlinear nature of the slope-erosion relationship. A difference in the trail slope-rock type relationship is evident as 14 sample sites on the volcanic rock (61%) were in slope classes greater than 12^0, whilst only 8 sites on the sedimentary rock (23%) fall into the same classes.

The distribution of sample sites on various types of terrain position is shown as Table 5.8. It is clearly shown that most of the sites on the volcanic rock (19 sites, 82.6%) belonged to the 'direct-ascent' type of trail, whether they be upper slope, lower slope or interfluve (catchment boundary). On the sedimentary rock, more sites (18 sites, 51%) belonged to the 'oblique' type of trail which passes across the terrain, though the 'direct-ascent' trail type also occupied a significant proportion (15 sites, 43%). Only a total of 5 sample sites were located on level ground.

Figure 5.3

Relationship between the slope gradients of the trail & its surrounding terrain.

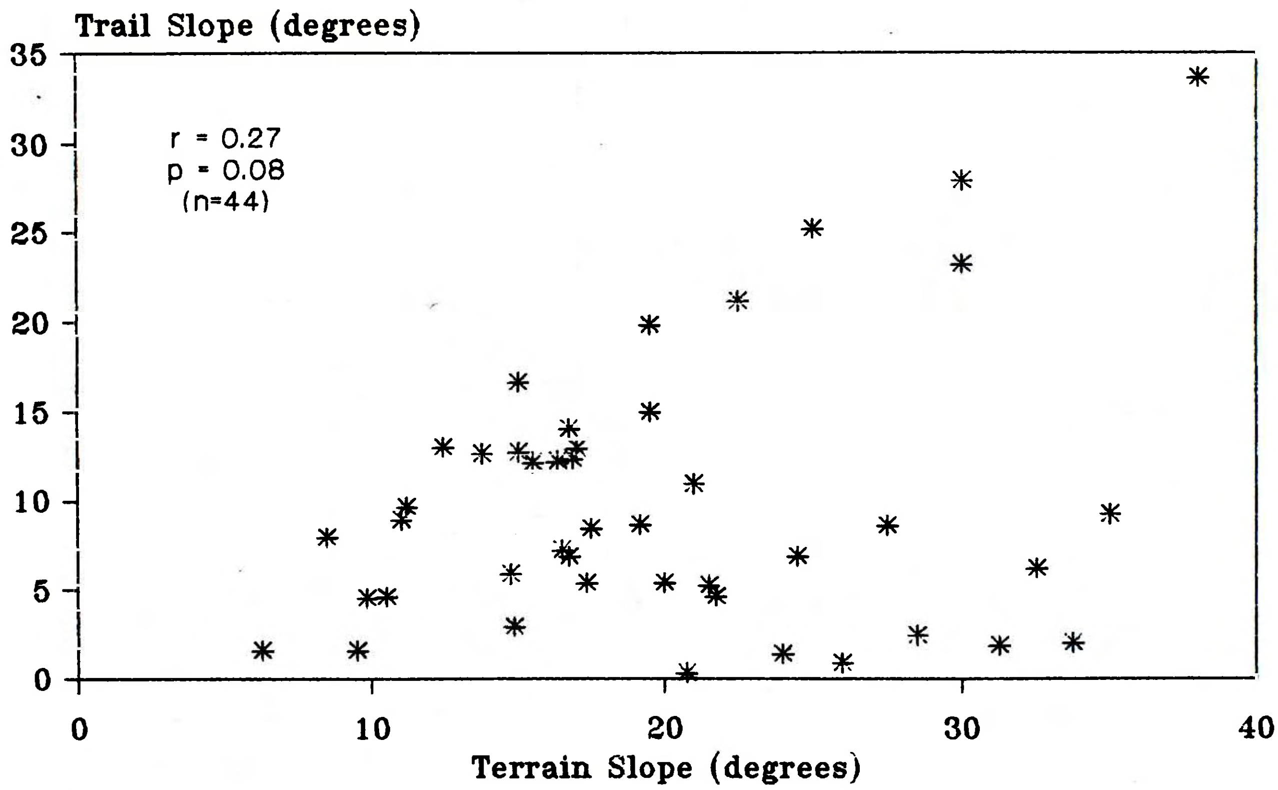


Table 5.7 The distribution of sample sites on different slope classes with respect to parent rock.

Rock	0-5°	5-12°	12-21°	> 21°	Row Total
Volcanic	2	7	9	5	23
Sedimentary	12	15	7	1	35
Column Total	14	22	16	6	58

Chi-Sq. Test: $p<0.05$ (df=3)

Table 5.8 The distribution of sample sites on different terrain positions with respect to parent rock.

Rock	Direct-Ascent on Upper slp	Direct-Ascent on Lower Slp	Direct-Ascent on Interfluve	Oblique at Sidehill	Level on Crest/Floor	Row Total
Volcanic	5	5	9	1	3	23
Sedimentary	4	3	8	18	2	35
Column Total	9	8	17	19	5	58

Chi-Sq. Test: $p<0.01$ (df=4)

To summarize, the sample sites along the study trail possess a wide range of environmental site conditions. Moreover, it is apparent that the environmental site condition, in terms of vegetation, parent material, topography and locational characteristics, varied between the volcanic rock and the sedimentary rock. Accordingly, in examining the environmental factors of trail degradation, particular attention must be given to disentangling the importance of environmental variables from the interference of rock type.

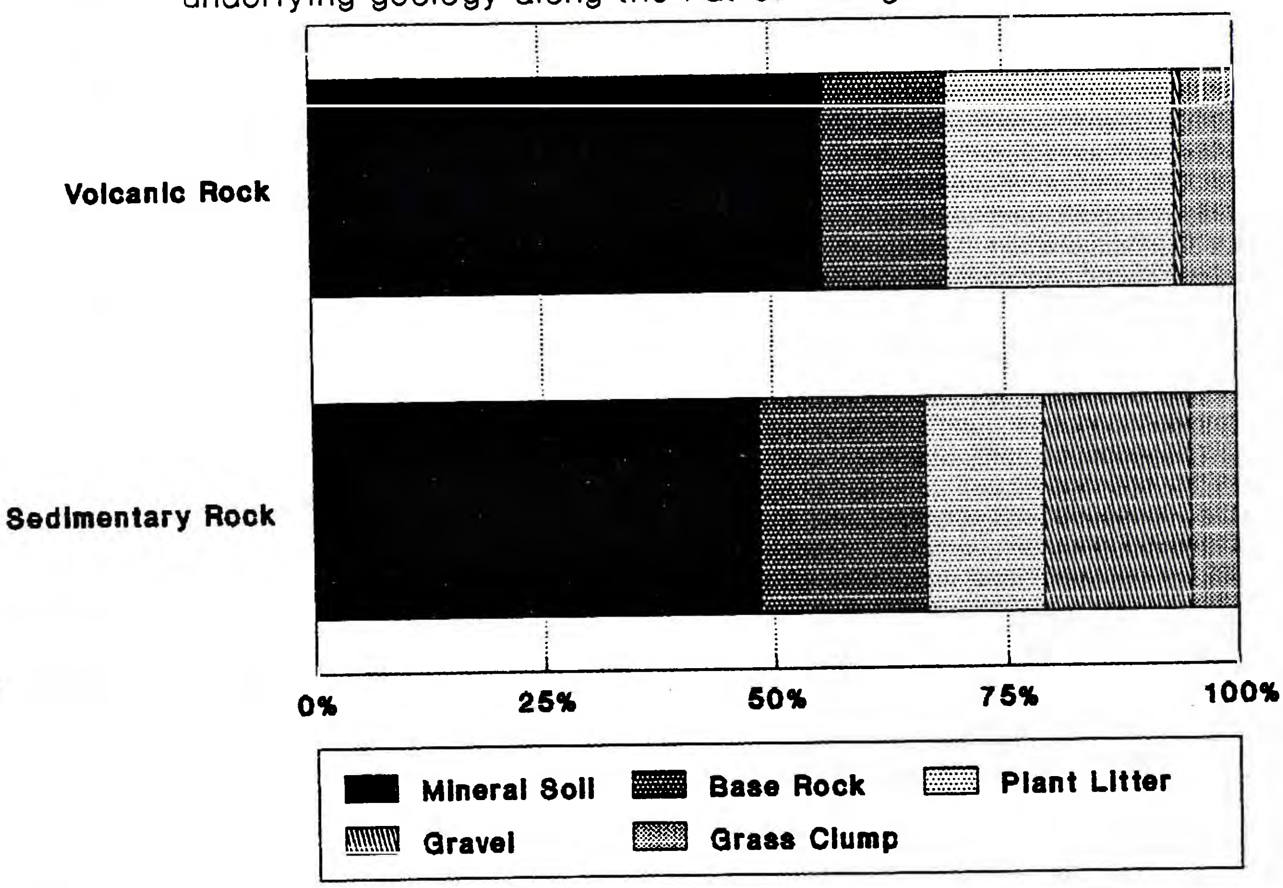
TREAD SURFACE MATERIAL

Situated in a subtropical environment, the PSR Trail receives an abundant rainfall of more than 2000 mm per year. Despite this, the rough terrain and the nature of parent material in the study area precludes the occurrence of high water-tables and muddy areas along most parts of the trail.

Unless there is intense management input, the material on the tread surface is generally associated with the parent material and vegetation community of the surrounding area. Figure 5.4 depicts the composition of surface material on the tread along the study trail. On both parent rocks, mineral soil was the major component on the tread surface. Nevertheless, there were important differences in the proportions of exposed base rock, plant

Figure 5.4

The composition of tread surface material with respect to underlying geology along the Pat Sin Range Trail.



litter and gravels between the two parent rocks.

The percentage of plant litter on the tread surface of the volcanic rock was double that of the sedimentary rock, whilst the tread surface on the sedimentary rock had a greater proportion of exposed base rock and loose gravel. Statistically, the only significant differences were amongst the percent plant litter and percent gravel.

The more frequent presence of plant litter in the area underlain by volcanic rock could be attributed to the greater richness of grassland in that area (Chang et al., 1989). Also, as mentioned earlier, the inherent abundance of gravels as the weathering product of the conglomerates and the shallow soil layer developed may explain the more frequent presence of bedrock and gravels of the tread surface of the sedimentary rock.

COMPACTION OF TRAIL TREAD

Although compaction is often a deliberate practice in trail design (Lucas, 1984), it is also liable to aggravate soil erosion (Hammitt & Cole, 1987). By comparing the penetration resistance at undisturbed and disturbed positions, as well as amongst different sites with similar design and maintenance standards, the degree of soil compaction can be evaluated. Relating compaction to trail morphological variables could also reveal the association of tread compaction and morphological degradation.

As mentioned in Chapter IV, there were varied sample sizes amongst different measuring positions across the tread as well as amongst different sample sites. Accordingly, the assumption of homogeneity-of-variance for parametric statistics such as ANOVA cannot be upheld in some analyses. Hence, both parametric and non-parametric statistics need to be employed.

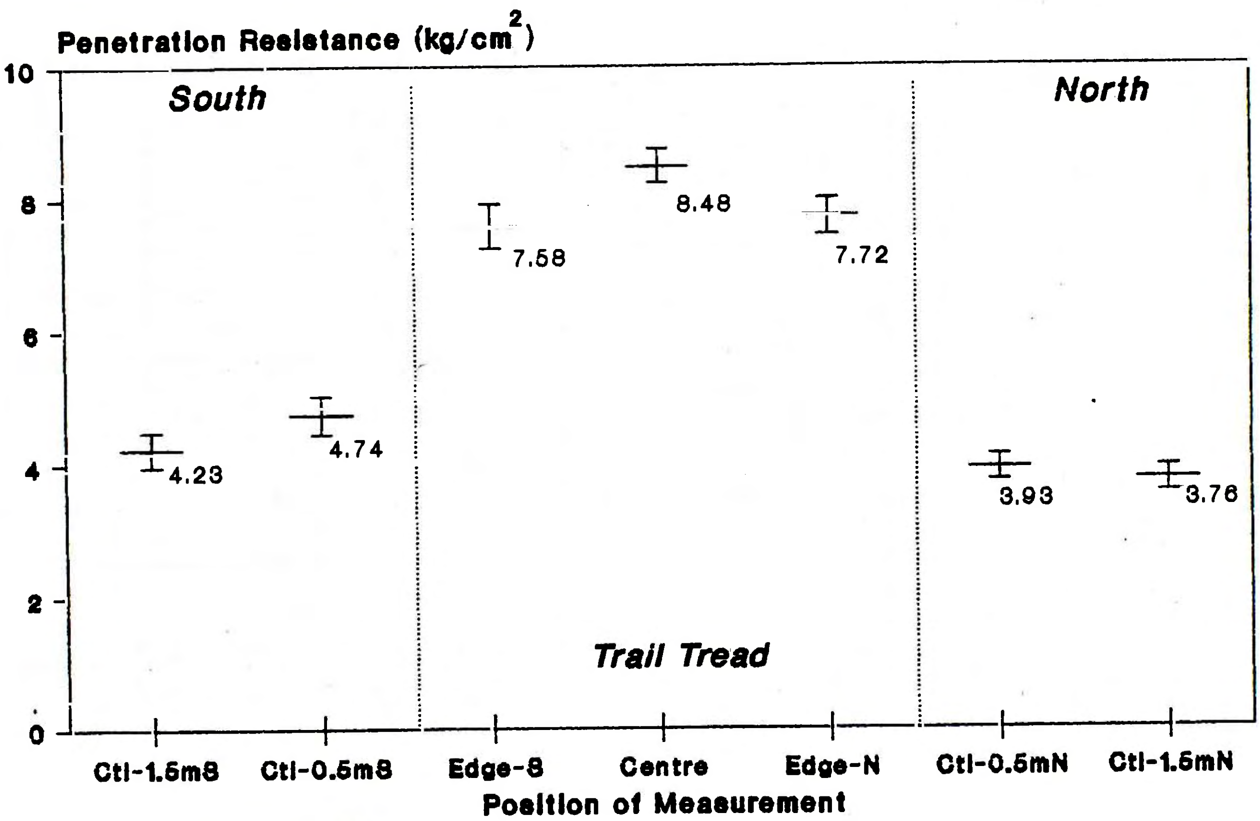
The mean penetration resistance recorded at 7 positions across the trail tread is shown in Figure 5.5. There was little variation in penetration resistance amongst the off-trail positions as well as amongst the on-trail positions, whilst sharp differences in penetration resistance were noted at the trail-edge positions. Moreover, penetration resistance was significantly lower on off-trail positions than that on the trail tread.

Table 5.9 illustrates the statistical comparison of the penetration resistance results amongst the individual positions across the trail tread. It can be seen that the major difference occurred at the boundary of the trail tread. The southern and northern edges exhibited pronounced increases in penetration resistance compared to that measured at 0.5m from the tread.

For the off-trail control positions, a significant

Figure 5.5

Mean penetration resistance* on and beside the tread of the PSR Trail.



* ± 1 standard error.

Table 5.9 Comparison of the differences in penetration resistance across the trail treads

Position	1.5m-S M=4.23[1] SE=.27 N=51	0.5m-S M=4.74 SE=.26 N=51	Edge-S M=7.58 SE=.33 N=44	Centre M=8.48 SE=.25 N=47	Edge-N M=7.72 SE=.28 N=48	0.5m-N M=3.93 SE=.19 N=52	1.5m-N M=3.76 SE=.19 N=55
0.5m-S	1.38[2] ns[3]	—	—	—	—	—	—
Edge-S	7.99 **	6.68 **	—	—	—	—	—
Centre	11.89 **	10.26 **	2.18 *	—	—	—	—
Edge-N	9.11 **	7.64 **	0.32 ns	-2.03 *	—	—	—
0.5m-N	*-0.41*[4] ns	*-2.39* *	*-7.17* **	*-8.08* **	*-7.58* **	—	—
1.5m-N	-1.48 ns	-3.00 **	*-7.26* **	-15.03 **	*-7.70* **	-0.63 ns	—

Note: [1] M=Mean; SE=Standard error of mean; N=Number of samples.
[2] T-Test (Separate variance estimate). The figure in all cells is t value, except that in italic form. Positive figure indicates penetration resistance of the row item is greater than that of the column item. Negative figure indicates the reverse case.
[3] Significance: ns = not significant (p>0.05); * = p<0.05; ** = p<0.01.
[4] Mann-Whitney Test. The figures in italic form are z-values. The meaning of figure's sign is similar to that of the T-Test.

difference was found only between 0.5m-S and 0.5m-N positions where the penetration resistance measured on 0.5m-S was higher than its counterpart of 0.5m-N. Whilst this can be regarded as inherent variation in penetrability in the environment, such a difference was not found at the trail-edge positions. This may indicate that penetration resistance at both edges of the tread has probably increased and reached the maximum level.

On the trail tread, there were also discernible differences between the edges and the trail centre; the penetration resistance at the centre of the trail was consistently higher than that measured at the edges of the trail. This may be indicative of the fact that the trampling force was concentrated towards the centre of the tread.

The penetration resistance data obtained from both sides of the trail (S and N) were merged together as four groups: 1.5m apart, 0.5m apart, trail edge, trail centre (Table 5.10). No significant difference could be detected between groups which were 1.5 m and 0.5 m from the trail tread. This result is similar to that of Dawson et al. (1974), suggesting that when trail treads become established and readily identified by hikers, compaction impact would be highly localized on tread surfaces.

For the two on-trail groups, the difference in

Table 5.10 Summary statistics and comparisons of penetration resistance at the four major positions across the trail tread.

Position of Measurement	Mean	Median	Std. Error	Range	Skewness of Data[1]
		(all in kg/cm^2)			
Off-trail groups	4.22	3.77	0.19	2.18-8.79	ns
1.5m apart(n=106)	4.03	3.52	0.19	2.02-9.27	ns
0.5m apart(n=103)	4.45	3.84	0.22	2.33-10.20	ns
1.5m VS 0.5m	[2]$t=1.50^{ns}$				
On-trail groups	8.06	7.92	0.25	4.52-10.20	ns
Trail Edge(n=92)	7.81	7.85	0.27	4.39-10.20	ns
Trail Centre(n=47)	8.48	8.77	0.25	4.77-10.20	ns
Edge VS Centre	$t=2.52^{*}$				
Off- VS On-trail	[3]$z=-13.25^{**}$				
Amongst 4 groups	[4]$\text{Chi Sq.}=179.47^{**}$				

[1] Kolmogorov-Smirnov Goodness-of-Fit Test (for normality).
[2] T-Test.
[3] Mann-Whitney Test.
[4] Kruskal-Wallis 1-Way ANOVA.
(Significance: ns = not significant; * = p<0.05; ** = p<0.01)

penetration resistance was much closer compared to off-trail groups, though statistical significance was also indicated between them.

Owing to the divergent nature of penetrability between the on- and off-trail positions, these data were further pooled into two major groups, i.e. off-trail and on-trail groups. They were significantly different from each other (Table 5.10).

To express the degree of compaction on the study trail, two indicators were computed from the penetration resistance data. Absolute change of penetration resistance (ABSCHG), the difference of mean penetration resistance between control and trail groups, is the absolute amount of change of penetrability at a sample site. Percent change of penetration resistance (PCTCHG), the ABSCHG divided by the mean penetration resistance of control group, reflects the relative aspect of penetrability change which may diminish the inherent difference in penetrability amongst different sites so that comparisons can be made.

Table 5.11 illustrates the descriptive statistics of the two compaction indicators. The average ABSCHG of the study trail was 4.05 kg/cm^2, ranging from 1.13 to the greatest of 5.25 kg/cm^2. On the other hand, the relative change of penetration resistance ranged from only 14.9% to as high as 188.7%, with an average change of 109.8%. This indicates

Table 5.11 Descriptive statistics of two compaction indicators.

Indicator	Mean	Median	Std. Error	Range	Skewness of Data[1]
ABSCHG (kg/cm^2)	4.05	4.15	0.19	1.13-5.25	ns
PCTCHG (%)	109.2	109.8	5.97	14.9-188.7	ns

[1] Kolmogorov-Smirnov Goodness-of-Fit Test (for normality).
ns: not significant

that the penetration resistance of the tread surface was double that of the off-trail zone. The increase in penetration resistance on the tread may also be associated with a reduced water infiltration rate. This change may promote the erosion of the tread surface, as more surface runoff moving on an already concentrated tread acts as to channel water.

Due to the differences in instruments used and soil conditions, the results of the present study are not comparable to other studies. However, in term of relative change of penetration resistance, they may be compared to some previous studies using a similar instrument, i.e. pocket penetrometer.

As shown in Table 5.12, many of the measurements of penetration resistance were conducted at campsites and in temperate forested areas. The degree of compaction in the present study, as assessed by the relative change, is less than other studies. Apart from the different nature of

Table 5.12 Relative changes of penetration resistance, in descending order, in some recreation impact studies using pocket penetrometer.

Geographic Location	Ecosystem Type	Location of Impact	Ave. P.R. at Controls	Rel. Change of P.R.(%)[1]	Data Source
Michigan, U.S.A.	Needleleaf Forest	Trail	0.24	1477	Ward & Berg, 1973
Arizona, U.S.A.	Desert Woodland	Campsite	0.70	337	Cole, 1986
Minnesota, U.S.A.	Needleleaf Forest	Campsite	1.40	164	Marion & Merriam, 1985
Rhode I., U.S.A.	Oak Forest	Recreation Site	1.25	144	Brown, Jr. et al., 1977
Hong Kong	Subtropical Grassland	Trail	4.22	109	Leung, present study
Montana, U.S.A.	Subalpine Forest	Campsite	2.20	71	Cole, 1983b

1 The mean relative difference between impact zone and its nearby undisturbed control site.

soils in these studies, the small change in penetrability found in this study may be attributed to the already high level of penetration resistance in the environment where the trail traverses.

MORPHOLOGY OF TRAIL TREAD

Apart from the compaction of the trail tread, morphological changes on trails are a more discernible type of physical degradation. The trail morphology variables examined in the present study include bare width of tread (tread width), incision depth of tread, cross-sectional area loss of tread, and the number of multiple parallel treads (or secondary treads) alongside the major tread.

The morphology of a trail has important implications on the durability and function of facilities and resource quality.

Tread Width

The loss of vegetation cover on treads creates bare ground surfaces which are subject to the direct impact of erosional agents. It may also produce unsightly scars in natural and semi-natural areas.

The results of the tread width measurements, together with other trail morphology variables, are provided in Table 5.13. There was great variation in tread width along the PSR Trail. Site 37A at Ping Fung Shan had the narrowest tread width of 34.4 cm whilst the multiple treads at Site 3, which was situated at the second crest of Pat Sin Leng, were in total 670.4 cm wide, a 20 fold increase. Whilst the average tread width was 99.8 cm, 50% of the sample sites had tread widths of 76.3 cm (30 inches) or less. These data were considerably positively skewed as the frequency distribution of tread width was found to deviated significantly from normality (Table 5.13). This indicates that there are a few localities where tread widths are exceptionally large.

Table 5.13 Summary statistics of the trail morphological variables along the Pat Sin Range Trail.

Variable	Mean	Median	Std. Error	Range	Skewness of Data[1]
Tread Width (BW) (cm)	99.8	76.3	11.4	34.4-670.4	**
Average Incision Depth (AID) (cm)	3.3	2.5	0.4	0.0-15.9	ns
Maximum Incision Depth (MID) (cm)	6.7	5.0	0.7	0.0-25.9	ns
Tread C-S Area (TCSA) (cm^2)	333.4	196.7	73.4	0.0-4171.2	**
Tread Surface Roughn.(SDDP)(cm)	2.0	1.5	0.2	0.0-7.5	ns
Form Ratio[2]	67.1	32.7	16.5	3.2-787.4	**

[1] Kolmogorov-Smirnov Goodness-of-Fit Test (for normality).
ns: not significant; **: $p<0.01$

[2] n=57. For all other variables in the table: n=58.

Comparing the average tread width measured in other studies, the PSR Trail is similar to those classified as the 'poor' in the Great Smoky Mountain National Parks of the United States (Bratton et al., 1979) (Table 5.14). It is also wider than many trails receiving heavier use. Notwithstanding the numerous environmental and use factors contributing to this difference, the situation of the PSR Trail should be a matter of concern for local resource managers. Aesthetically, the trail criss-crosses on open grassland, and the bare scars of trail tread can be viewed from all sides, irritating recreationists.

Table 5.14 Comparison of the results of several trail degradation studies in different environments.

Trail	*Location*	*N*	*Tread Width (cm)*	*Ave. Depth (cm)*	*Max. Depth (cm)*	*C-S Area (cm^2)*	*Data Source*
Pat Sin Range Trail	Hong Kong	58	99.8 (11.39)	3.3 (0.36)	6.7 (0.71)	333.4 (73.38)	Leung, present study
Appalachian Trail	Eastern U.S.A.	221	76.5 (2.06)	6.4 (0.29)	NA	312.3 (22.35)	Burde & Renfro, 1986
Poor trails in GSMNP[1]	Eastern U.S.A.	623	101-113	NA	7.4-7.7	NA	Bratton et al., 1979
Good trails in GSMNP	Eastern U.S.A.	414	40-84	NA	1.2-2.3	NA	Bratton et al., 1979
Big Creek Trail (SBWW[2])	Western U.S.A.	10	80->81 [9]	NA	13->15 [3]	1187-> 1155 [47->43]	Cole, 1983a & 1991
Trails in SBWW	Western U.S.A.	69	NA	NA	NA	5894.5	Helgath, 1975
Pangnirtung Pass	Arctic Canada	25	28.7	4.3	NA	NA	Welch & Churchill, 1986
Bannerman's Hut Path	South Africa	44	62.4	18.0	NA	132	Garland et al., 1985
Giant's Ridge Path	South Africa	89	49.9	16.7	NA	76	Garland et al., 1985
Contour Path Path	South Africa	51	40.7	12.5	NA	54	Garland et al., 1985

Note: (fig.) -- Standard Error
[fig.] -- 95% Conf. Intv.

1 GSMNP: Great Smoky Mountain National Park
2 SBWW: Selway-Bitterroot Wilderness

Although there are no specific trail design and maintenance standards available for local country parks, standards employed in other countries could be utilized for evaluation. Two different tread width standards are found in the trail literature. One is the Forest Service Standard (FSS) mentioned by Cole (1987) in his review paper. The FSS stated that maximum tread width should not exceed 61 cm. Another standard is the Trail Design

Standard (TDS) illustrated in a widely-used forestry handbook (Lucas, 1984). The TDS recommends a less stringent tread width standard of 70 cm.

When considering the FSS, there were 45 sites (77.6%) along the PSR Trail that exceed this standard. Moreover, 13 sites (23.4%) were double the standard width. This percentage of exceedance was lowered to 56.9% (33 sites) when evaluated by the TDS. Both of these comparisons suggest that the PSR Trail is not in good condition in terms of trail widening.

Incision Depth

Trail incision or deepening represents a more serious degradation problem of trail erosion. Incised tread surfaces often play a role similar to that of rills and gullies on which concentrated and channelized flows are formed. Consequently, the normal function of a trail for transport purpose would be impaired.

The results of the present study clearly show that trail incision along the Pat Sin Range is not as serious a problem as compared to other trail routes. The average incision depth was 3.3 cm, with a minimum of zero (no incision at all) at Site 39A near Wong Leng and a maximum of 15.9 cm at Site 32 (Table 5.13). This condition is the best amongst those trails listed in Table 5.14.

Nevertheless, in many trail degradation studies, trail incision was assessed not by the averaged data, but by the maximum incision depth, which possibly better reflects the degree of incision. For the PSR Trail, the maximum incision averaged 6.71 cm, which is reasonably good when compared to trails in North America and South Africa. However, it should be noted that along the study trail there are several sites where incision was particularly serious. These include Sites 3, 32, 41A and 44.

There are no established standards for incision depth, but the trail incision along the PSR Trail may be compared to several criteria used by other researchers. Bayfield & Lloyd (1973), Bratton et al. (1979) and Cole (1983a) employed varied criteria to define a trail segment where incision had created a rutting or gullying problem. As shown in Table 5.15, the PSR Trail is generally in good condition except for the extremely stringent criterion of 5 cm used by Bayfield & Lloyd (1973). There were only 3 and 2 sites which exceeded the criteria of 15 cm and 25 cm respectively.

Table 5.15 Selected criteria for trail incision problems.

Reference	Criteria	No. of Sites of PSR Trail Exceeded	% sites of PSR Trail Exceeded
Bayfield & Lloyd, 1973	5 cm	29	50
Bratton et al., 1979	15 cm	3	5.2
Cole, 1983a	25 cm	2	3.5

Tread Cross-Sectional Area

Tread cross-sectional area (TCSA) was measured in this study to estimate the degree of trail erosion and its resultant soil loss. As shown in Table 5.13, the mean TCSA was 333.4 cm^2, with a range from zero cm^2 (no incision) at Site 39A to as much as 4171.2 cm^2 at Site 3. About 50% of the sample sites had TCSAs of 196.7 cm^2 or less. Similar to the result of tread width, the positively skewed data indicates that there are only a few sites where soil losses on tread were exceptionally high.

Although the differing techniques of cross-sectional measurement may have produced slight differences amongst the different studies, a general comparison could still be made. As shown in Table 5.14, while the average soil loss in the PSR Trail is much less than that for the Big Creek Trail and other trails located in the Selway-Bitterroot Wilderness in Montana, it is still high when compared to the mediterranean climate in South Africa.

No standards have been set for the loss of soil from a trail tread, but the results of this study suggest that special management attention should be paid to several badly eroded sites.

Multiple Treads

Multiple treads, or secondary paths, are essentially a form or stage of trail widening. The primary cause is the difficulty of footing, actual or perceived, on the original tread.

Along the PSR Trail, multiple treading was no more a serious problem than those trails passing through wet areas (Hammitt & Cole, 1987). The steep slopes at both sides of the PSR Trail further restricted hiker wandering except at limited localities.

There were only 5 sites where more than one tread existed, constituting only 8.6% of all sites (Table 5.16). Moreover, 4 of the these 5 sites had only one additional tread, whilst there were 4 parallel treads alongside Site 3, which is situated on a steep slope.

Table 5.16 The multiple treading problem in the Pat Sin Range Trail.

No. of Tread(s)	No. of Sites	Percentage
1	53	91.4
2	4	6.9
4	1	1.7

Other Morphology Variables

Two additional morphology variables: Tread surface roughness from the standard deviation of the incision measurements, and Form ratio, the tread width divided by the average incision depth, were derived (Table 5.13). The results show that the variation in incision depths was generally small, though the largest value reaching 7.49 cm.

Results of the tread shape, as indicated by the form ratio, showed significant skewness and great variation. While uneven tread surfaces do not impair trail functioning, it has been shown that hikers would be uncomfortable when passing through narrow and deep treads. Such a situation was found only at Site 32 where the form ratio was 3.2, the lowest amongst the sample sites.

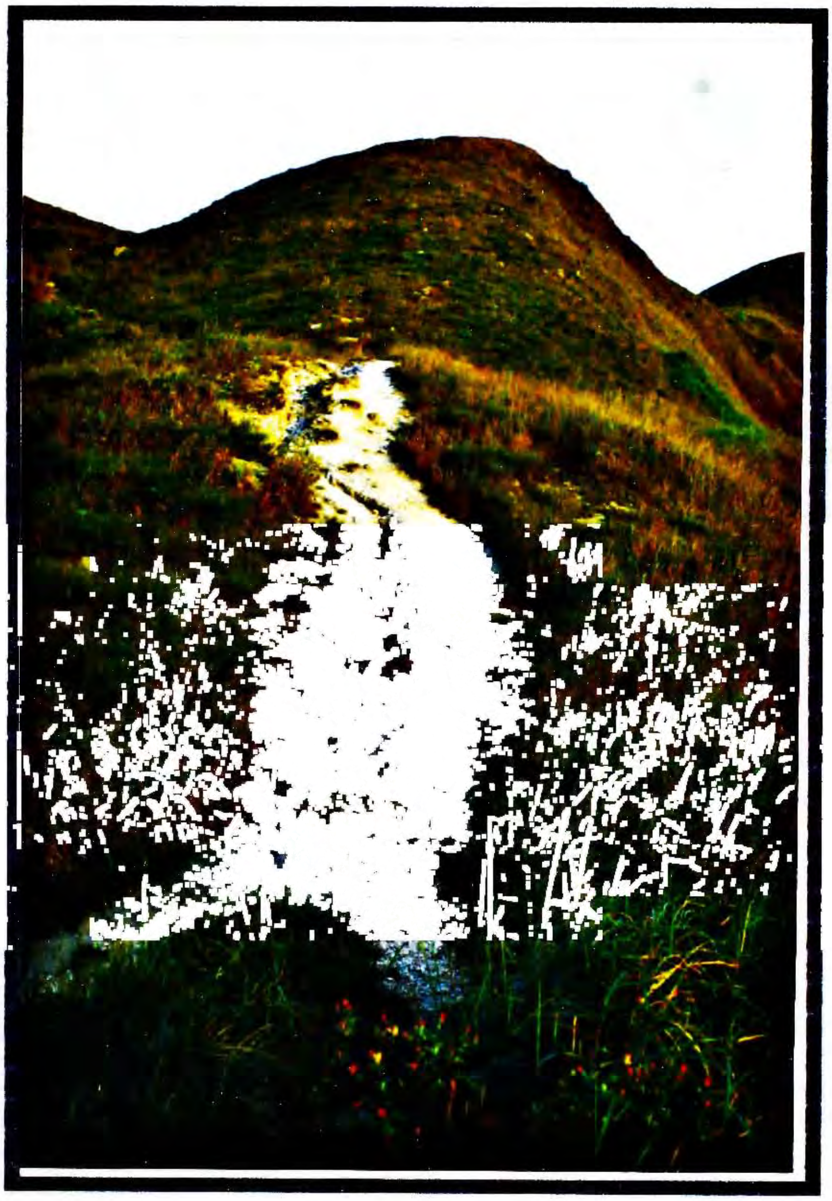
OVERALL EVALUATION

Other Evidence of Degradation

The above discussion was based on the information obtained from the systematically-sampled sites. However, there were also severely-degraded localities that were not sampled due to the sampling framework (Refer to Chapter IV). Plates 5.1 and 5.2 illustrate two rutted trail segments that exist in the vicinity of Wong Leng. The trail condition shown in Plate 5.1 may force hikers to avoid the deeply-incised rut and walk either side of the tread. This will probably lead to further trail widening,

Plate 5.1 A rutted trail segment near Wong Leng at the central part of the PSR Trail.

Plate 5.2 Another rutted trail segment at the vicinity of Wong Leng.



especially in this open trail corridor.

Such a situation is probably duplicated at the site shown in Plate 5.2, but the stony trail tread (outwash deposits) can be an additional factor contributing to hiker wandering, particularly when hikers find the tread uncomfortable to walk on.

Other evidence of physical degradation, and deterioration of the trail system at large, which are beyond the scope of this study, were found along the trail. They include the large bare cores at trail junctions near Wong Leng and Ping Fung Shan, and on a number of crests at Pat Sin Leng. In addition, informal shortcuts were found at the switchbacks near Wong Leng and informal by-pass tracks at the ridges of Pat Sin Leng.

Summary Rating

The preceding discussion focuses on the results of individual degradation-indicator variables. In addition to this information, however, it would be useful for park managers if there were an overall assessment using a single index by which various aspects of trail degradation could be reflected.

The idea of integrating individual variables into a single summary rating is not new in recreation impact research, especially in campsite studies (Marion, 1984).

However, the use of a summary rating for trail degradation is less frequent and most of the rating systems involved subjective descriptions of site condition. The 'Erosional Stages' by Ketchledge & Leonard (1970) and the 'Erosion Classes' by Summer (1980) are examples of descriptive rating systems.

Bayfield & Lloyd (1973) assessed the Pennine Way in the United Kingdom by using an objective index called the 'Index of Extent'. However, the index considered only different measures of trail width. A comprehensive 'Trail Index' was attempted by Welch & Churchill (1986), which combined the normalized values of bare width, trail depth, total trampled width, and absolute vegetation cover loss. However, no detail information was given for this index.

A single index was derived for this study with the aim to objectively evaluate the overall trail degradation condition. The z-score standardization method was employed. Z-scores of the tread width, maximum incision depth, cross-sectional area and multiple treading were computed and then summed into a single index -- the Degradation Score (DEG).

The selection of variables for computing the DEG is based on (1) the impact of these variables on trail function and aesthetic quality and (2) the effect of the variables on further degradation. Hence, only the variables representing bare ground, rutting and erosion were included. The individual parameters were standardized and summed without weighting since it was believed that each of the four parameters reflects an equally important aspect of trail degradation.

Table 5.17 lists the process of data standardization and the final DEG score for each site. The mean of the z-scores for each parameter is zero with a standard deviation of 1. When the parameters were combined into one value, the mean of the DEG scores remained unchanged, but the median was changed to -0.15, indicating that the majority of the sites had below-average DEG scores and that exceptionally high DEG scores were limited to only a few sites.

Altogether there were 39 sites whose DEG score was less than zero and 19 sites (32.8%) with DEG scores greater than zero. Sites with above-average DEG scores were classified as 'Degraded Sites' since the overall degradation condition on these sites are worse than the majority of samples. In contrast, those with DEG scores less than zero were categorized as 'non-degraded' sites.

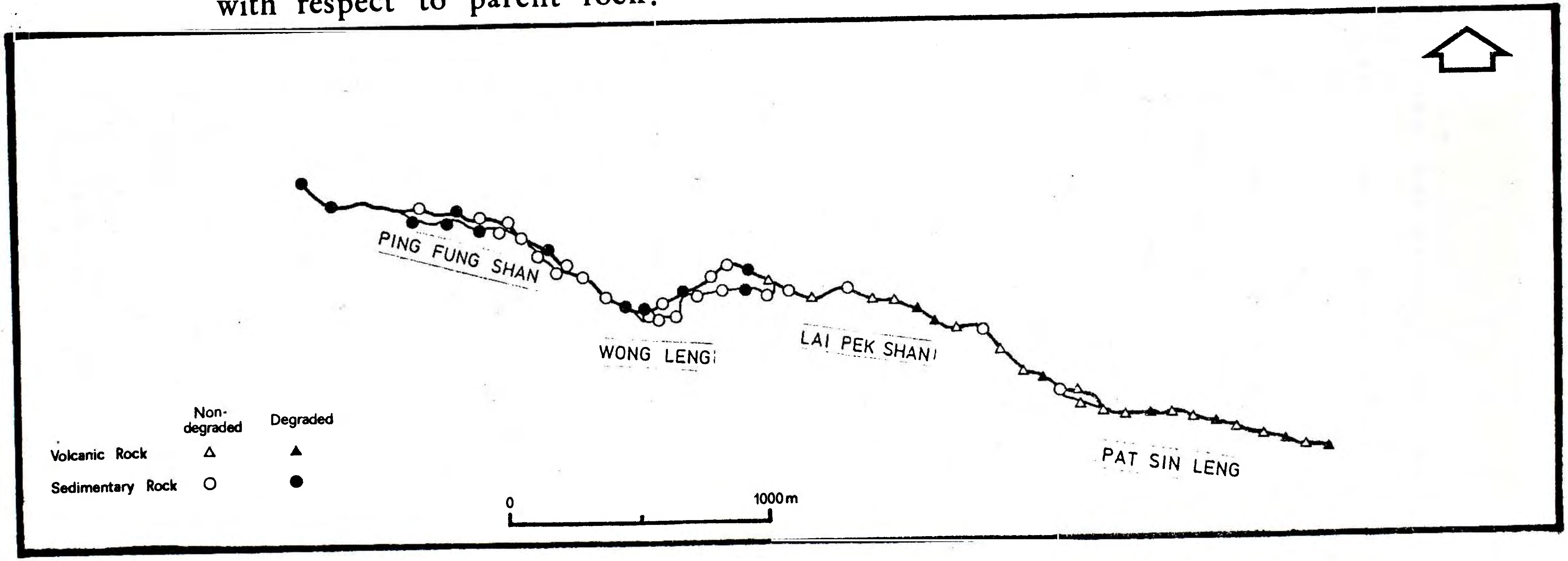
The degradation class of the sites along the study trail was mapped as Figure 5.6 with respect to parent rock. It can be seen that the degraded sites are distributed regularly along the study trail, but that sites near Wong

Table 5.17 The z-scores of the parameters for computing the summary Degradation Score.

Site	Z-BW	Z-MID	Z-TCSA	Z-MLTTD	DEG
1	.82564	.20106	.25784	1.90414	.80
2	-.43515	-.60912	-.35850	-.26135	-.42
3	6.57558	3.55488	6.86700	6.23513	5.81
4	.15276	-.74817	-.47686	-.26135	-.33
5	.57041	-.36996	-.14607	-.26135	-.05
6	-.31480	-.35328	-.33421	1.90414	.23
7	.79895	-.49418	-.38570	-.26135	-.09
8	-.36604	.29932	-.06246	-.26135	-.10
9	.34836	.43466	.42110	-.26135	.24
10	-.57255	-.83531	-.47310	-.26135	-.54
11	-.66572	-.04366	-.30258	-.26135	-.32
12B	-.11720	.13988	-.01651	-.26135	-.06
12A	-.40073	.08797	-.20560	-.26135	-.19
13	.22367	-.47378	-.09116	-.26135	-.15
14	.00316	.18067	.12269	-.26135	.01
15	-.51336	-.82048	-.44950	-.26135	-.51
16	-.32811	-.37182	-.27358	-.26135	-.31
17	-.40004	-.21608	-.16445	-.26135	-.26
18	-.27089	-.82604	-.47393	-.26135	-.46
19	.28608	1.06315	.20925	-.26135	.32
20	-.08188	-.19198	-.29149	1.90414	.33
21	-.63645	-.87795	-.50814	-.26135	-.57
22	-.41681	-.65547	-.44155	-.26135	-.44
23	-.05187	-.67401	-.43124	-.26135	-.35
24	.49148	-.54423	-.27366	-.26135	-.15
25	-.34979	-.21608	-.24470	-.26135	-.27
26B	-.42540	-.83531	-.51251	-.26135	-.51
26A	-.65278	-.70182	-.46949	-.26135	-.52
27B	.44084	.55887	.38726	-.26135	.28
27A	.74780	.55331	.25823	-.26135	.32
28B	-.00424	-.88351	-.42696	-.26135	-.39
28A	-.39878	-.70182	-.37111	-.26135	-.43
29B	-.36360	-.62581	-.40305	-.26135	-.41
29A	.15792	-.32361	-.12517	-.26135	-.14
30B	.92596	1.16698	.29436	-.26135	.53
30A	-.71306	-.76856	-.50925	-.26135	-.56
31B	-.09103	.26966	-.05126	-.26135	-.03
31A	-.70903	-1.20610	-.59354	-.26135	-.69
31C	-.33489	-.11597	-.06688	-.26135	-.19
32	-.56647	2.49441	.67482	-.26135	.59
33	1.47663	1.28934	.31240	-.26135	.70
34	-.67242	-.19940	-.25846	-.26135	-.35
35	-.47909	-.38109	-.33570	-.26135	-.36
36B	-.23245	-1.00587	-.57668	-.26135	-.52
36A	-.42636	.21775	.03177	-.26135	-.11
37B	-.40834	.86478	.00348	-.26135	.05
37A	-.75336	-.84272	-.56932	-.26135	-.61
38	-.10932	-.61283	-.37290	-.26135	-.34
39B	-.57764	.42539	-.13027	-.26135	-.14
39A	.08793	-1.24318	-.59657	-.26135	-.50
40B	-.47021	.10465	-.11709	-.26135	-.19
40A	-.23176	-.75002	-.41319	1.90414	.13
41B	-.08034	.61820	.32775	-.26135	.15
41A	.11916	3.55859	1.02544	-.26135	1.11
42B	.44898	-.43114	-.00495	-.26135	-.06
42A	-.39993	.94265	.34507	-.26135	.16
43	.05189	.40870	.49137	-.26135	.17
44	.28867	1.51552	1.27952	-.26135	.71

BW=Tread Width; MID=Max. Incision Depth; TCSA=Tread Cross-Sectional Area; MLTTD=Multiple Treading; DEG=Degradation Score.

Figure 5.6 Degradation class of the sample sites along the PSR Trail, with respect to parent rock.



Leng and Ping Fung Shan nevertheless have a greater chance of being classified as degraded sites.

The specific descriptions of several 'degraded' sites, where particular degradation problems can be illustrated, will be given in the Appendix with management recommendations.

REMARKS

The results of this study indicate that widening of the trail tread is the most noticeable problem along the Pat Sin Range Trail. Other forms of degradation, such as trail incision, cross-sectional area loss and multiple treading, are less serious. The overall condition of the trail is generally good. However, there are several sites where exceptionally severe degradation does occur and this may be related to the associated specific conditions at those sites. This relationship between degradation and site environmental condition will be evaluated in the next chapter.

CHAPTER VI

ENVIRONMENTAL INFLUENCES ON TRAIL DEGRADATION

INTRODUCTION

The preceding chapter illustrated the environmental site conditions along the portion of the PSR Trail under study. The degradation condition of the trail has been assessed by individual degradation-indicator variables as well as by a summary rating score. The results demonstrate considerable variations in degradation condition amongst the sample sites. The intent of this chapter then, is to account for such variations via a comparison to their inherent site conditions.

The parent material information were obtained from off-trail zones where inherent conditions were assumed, whilst the locational variables were measured at both on- and off-trail zones. The focus of this study is on the role of the various environmental factors, but use-related factors that interact with environmental influences will also be discussed. Although there is no use records for the PSR Trail, rough use information is given below in order to have a general picture on the use situation.

Rough estimates were obtained by counting of and interviewing with hikers for 30 working days throughout a year. The annual average number of hikers was conservatively estimated to range between 2500 to 6500. The proportion of westward and eastward walking was about 4:1. The majority of hikers preferred the By-Pass trail branches to Crest-Climbing trail branches.

BRANCHING EFFECT OF TRAILS

As a difference in use intensity occurs between the By-Pass (BP) branches and Crest-Climbing (CC) branches, this section attempts to ascertain if there is any difference in site condition and physical degradation between them.

As expected, nearly all of the CC branches were direct-ascent trails, though their exact positions on the slopes varied. Similarly, most BP branches were oblique trails which pass by at sidehills (Table 6.1a). Because the branches are related to trail position, the two types varied also in steepness. The average slope of the sample sites on CC branches was 10.34^0 and about 79% of the sites were greater than 5^0. In contrast, only 46% of the sites on BP branches had the same steepness; and the average slope was 5.99^0. The difference in steepness was fairly obvious. (Table 6.1 b & c).

Table 6.1 Locational differences of the sample sites on branch segments.

(a) Trail Position on Slope

Branch	Trail Position					
	DA- Upp Slp	DA- Low Slp	DA- Interfluve	OB- Sidehill	LV- Crest/Floor	No. of Sites
Crest-Climbing	3	4	5	1	1	14
By-Pass	0	0	1	12	0	13
No. of Sites	3	4	6	13	1	27

Chi-Sq. Test: $p < 0.01$ (df=4)

(b) Trail Slope Class

Branch	Slope Class				
	$0-5^0$	$5-12^0$	$12-21^0$	$>=21^0$	No. of Sites
Crest-Climbing	3	5	4	2	14
By-Pass	7	4	2	0	13
No. of Sites	10	9	6	2	27

Chi-Sq. Test: not significant (df=3).

(c) Trail Slope

Branch	n	Mean	Standard Error	Mann-Whitney Test: Z-Value	Significance
Crest-Climbing	14	10.34	1.79	-1.92	0.06
By-Pass	13	5.99	1.54		

Statistical comparisons were performed for the individual degradation-indicator variables and the summary degradation score (DEG) for each of these trail branch types. Although most of the variables on the BP branches attained higher values, no significant differences were detected for any of these variables between the types of branch (Table 6.2).

Overall, 19 branch sites were classified as 'non-degraded' whilst 8 were classified as 'degraded' sites (30%) (Table 6.3). The distribution of both categories on CC and BP branches was quite even. This result indicates that though there were probably differences in use-intensity between the two types of branch, they exhibited similar levels of degradation. This similarity may be attributed to the fact that the two types of branch received different yet equally high levels of use, at which point the effect of use-intensity is no longer deterministic. Since no discernible 'branching' effect can be identified, the branch sites were pooled for subsequent analysis.

Table 6.2 Comparison of degradation-indicator variables between the two types of branch.

Variable	Abbrev.	Crest-Climbing Branches (n=14)	By-Pass Branches (n=13)	Difference[1]
Trail Compaction				
Absolute Change of Pen. Res.(kg/cm^2)	ABSCHG	3.85[2] (0.57)	4.38 (0.30)	ns
Relative Change of Pen. Res. (%)	PCTCHG	93.44 (19.11)	111.25 (6.18)	ns
Trail Morphology				
Tread Width (cm)	BW	75.55 (9.86)	93.40 (10.54)	ns
Average Incision Depth (cm)	AID	3.16 (0.77)	3.26 (0.55)	ns
Maximum Incision Depth (cm)	MID	6.21 (1.78)	6.86 (1.07)	ns
Tread Cross-Sectional Area (cm^2)	TCSA	243.20 (68.78)	280.68 (49.06)	ns
Tread Surface Roughness (cm)	SDDP	1.96 (0.28)	1.73 (0.50)	ns
Form Ratio	FMRATIO	89.22 (58.45)	77.73 (39.14)	ns
Summary Rating				
Degradation Score	DEG	-0.16 (0.13)	-0.10 (0.09)	ns

1 Mann-Whitney Test (ns: not significant).
2 Mean value with standard error in bracket.

Table 6.3 The distribution of the sites on branch segments in different degradation classes.

Branch	Class: Non-Degraded	Class: Degraded	No. of Sites
Crest-Climbing	10	4	14
By-Pass	9	4	13
No. of Sites	19	8	27

Chi-Sq. Test: not significant (df=1)

PARENT MATERIAL

Parent rock

It was demonstrated in the Chapters III and V that the vegetation communities and soil properties were associated with the parent rock. Accordingly, the type of parent rock may reflect two physiographic zones. If a relationship between trail degradation and soil properties can be established, it may also be reflected through the two parent rocks.

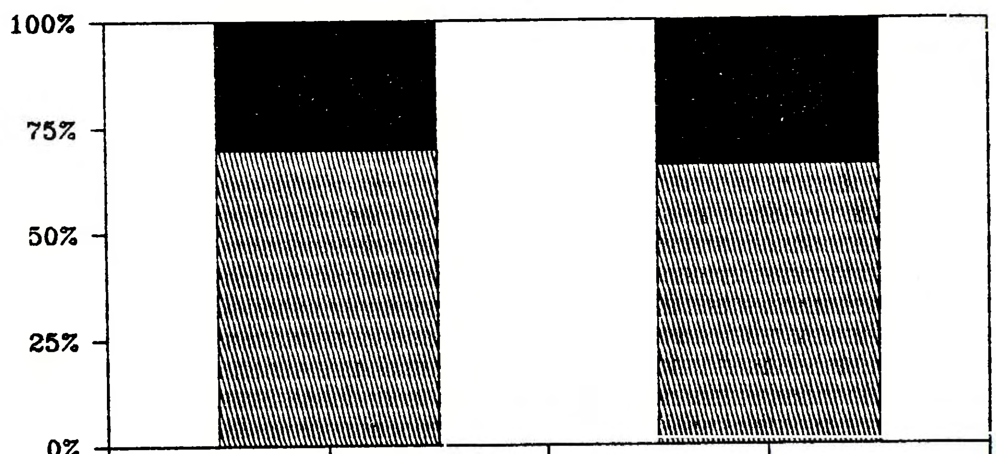
However, none of the degradation-indicator variables varied significantly between the parent rocks, though higher average values of tread width, cross-sectional area, relative change of penetrability and degradation score were associated with volcanic rocks (Table 6.4). Furthermore, there was minor difference in the proportion of 'degraded' sites between the two parent rocks (Figure 6.1).

Table 6.4 Comparison of degradation-indicator variables between the two parent rocks.

Variable	Volcanic Rock (n=23)	Sedimentary Rock (n=35)	Difference[1]
Trail Compaction			
ABSCHG	3.74 [2] (0.29)	4.32 (0.24)	ns
PCTCHG	118.94 (8.54)	100.54 (8.13)	ns
Trail Morphology			
BW	116.78 (26.46)	88.60 (7.33)	ns
AID	2.58 (0.33)	3.73 (0.54)	ns
MID	6.09 (1.07)	7.11 (0.95)	ns
TCSA	379.38 (175.12)	303.20 (43.06)	ns
SDDP	1.89 (0.30)	1.99 (0.27)	ns
FMRATIO	59.63 (11.70)	72.18 (26.63)	ns
Summary Rating			
DEG	0.12 (0.27)	-0.08 (0.07)	ns

[1] Mann-Whitney Test (ns: not significant).
[2] Mean value with standard error in bracket.

Figure 6.1
The occurrence of degraded sites on the two parent rocks.



	Volcanic Rocks	Sedimentary Rocks
Total Sites	23	35
% Degraded	30.4	34.3
Degraded (DEG>0)	7	12
Non-Degraded (DEG<0)	16	23

Chi-Sq. Test: Not Significant.

Non-Degraded (DEG<0)   Degraded (DEG>0)

Soil Properties

Similar to the situation for parent rock, the relationship between trail morphology and soil properties was generally weak (Table 6.5). There was only a significant positive relationship between average incision and percent silt, and an inverse relationship between average incision and percent clay. This suggests that trail incision is associated with the finer fractions in the soil. The divergent relationships identified may be attributed to the higher erodibility of silt contrasting with clay.

Similar associations were reported by Welch & Churchill (1986), but they found only a general positive relationship between trail depth and 'finer texture', whilst the results presented here demonstrate contrasting relationships of silt and clay content.

Despite the close relationships of clay content to clay ratio and aggregate stability (>1mm%) (Refer to Chapter 5), no significant relationships were found between these erodibility indexes and morphological degradation of the trail. Whilst aggregate stability and clay ratio have been proven effective in estimating the susceptibility of agricultural soils to erosion (Morgan, 1986; Lal, 1988),

Table 6.5 Correlation between soil properties and trail morphology.

Variable	BW	AID	MID	TCSA	SDDP	FMRATIO	DEG
STONIN	-0.19	0.01	-0.06	-0.14	-0.12	0.09	-0.20
SAND%	0.13	0.08	0.17	0.09	0.11	0.01	0.08
SILT%	-0.26	0.33*	0.07	-0.10	0.06	0.05	-0.14
CLAY%	0.01	-0.27*	-0.22	-0.03	-0.15	-0.05	-0.00
CLAYRAT	0.12	0.04	0.15	0.06	0.10	-0.00	0.06
ITU	0.09	0.13	0.20	0.06	0.16	0.00	0.06
PH	-0.09	0.08	0.04	-0.04	0.04	-0.02	-0.08
OM%	-0.06	-0.14	-0.19	-0.09	-0.17	-0.00	-0.09
ASMWD	0.05	-0.12	-0.05	-0.02	-0.04	0.12	-0.00
AS1MM%	0.13	-0.19	-0.12	0.07	-0.08	0.10	0.08

Pearson Correlation Coefficient: * - $p<0.05$

their poor performance in this study indicates that they may be irrelevant to trail degradation in which rill- and gully-type of erosion are the important components.

Contrary to the trail morphology, trail tread compaction, as indicated by the absolute change (ABSCHG) and relative change (PCTCHG) of penetration resistance, exhibited significant relationships with soil textural variables and organic matter content (Table 6.6). The absolute penetrability change was positively related to the percent sand, clay ratio and index of textural uniformity and inversely related with percent clay. It suggests that the more homogeneous soil texture towards the sand fraction contributes to a greater change in penetrability. The results contradict the common thought that the compaction potential is greater in a soil with heterogeneous textural composition or with a low sand fraction.

Table 6.6 Correlation between soil properties and compaction-indicator variables.

Soil Variable	Compaction-Indicator Variable	
	ABSCHG	PCTCHG
STONIN	0.14	-0.13
%SAND	0.35*	0.13
%SILT	-0.14	-0.30*
%CLAY	-0.29*	0.18
CLAYRAT	0.34*	0.02
ITU	0.31*	-0.04
PH	0.18	0.19
%OM	0.06	0.38**
ASMWD	0.06	0.25
AS1MM%	-0.12	0.20
MPRCT	-0.13	-0.61**

Pearson Correlation Coefficient (Significance: * - $p<0.05$; ** - $p<0.01$).

For the relative change in penetration resistance, there were significant correlations with percent silt, organic matter content and mean penetration resistance at off-trail positions (MPRCT). The relationship between relative penetrability change and organic matter content suggest that organic matter in the pre-trail environment may be an important hint to the prospect of compaction. This finding could be explained by the fact that the presence of organic matter in soil helps adsorb water onto the surfaces of soil particles. This results in a lower soil density and susceptibility to compaction when subject to trampling force, especially when dry. The significant negative relationship between organic matter and the mean penetration resistance at off-trail controls (r = -0.57,

$p<0.01$) supports this argument.

On the other hand, the relative change of penetrability is also controlled by the original penetrability level. Soils with inherently high penetration resistance would have little prospect of being further compacted relative to those with lower original penetration resistance.

Figure 6.2 depicts the change of penetration resistance from the farthest position to the centre of trail tread with respect to different soil textural classes. While the inherent difference in penetrability determined the final compaction status, clay loam experienced the greatest degree of change. This finding confirms that the finer composition of clay loam could be subject to more compactness than a less variable coarse soil with its inherently greater compactness (Brady, 1990). The result also supports the relationship between penetration resistance at off-trail controls and its relative change on the tread.

For the overall condition, the summary DEG score did not relate to any of the soil properties measured (Table 6.5). Nor is there any significant association between soil textural class and the occurrence of 'degraded' sites, though the proportion of 'degraded' sites was higher in sandy loam areas (Figure 6.3).

Figure 6.2
Change of penetration resistance across the tread with respect to soil texture.

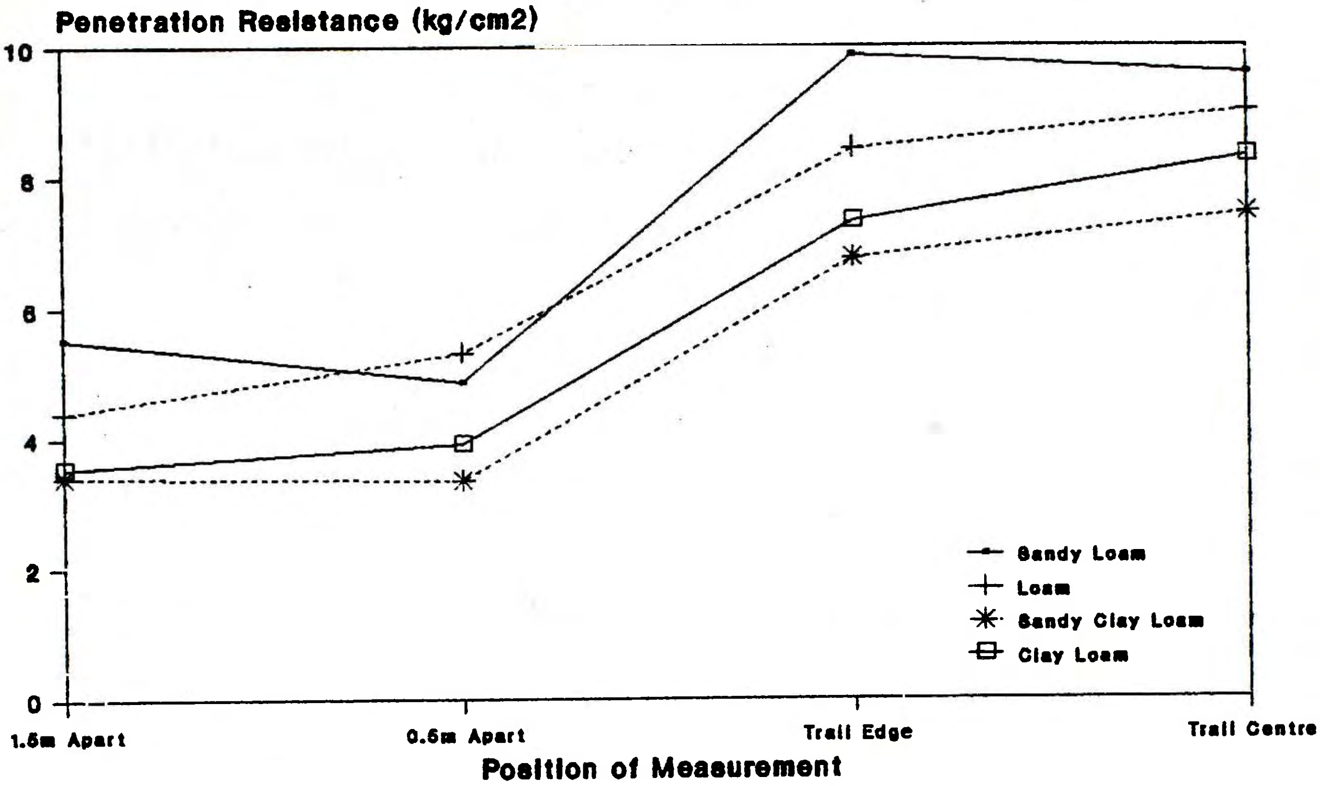
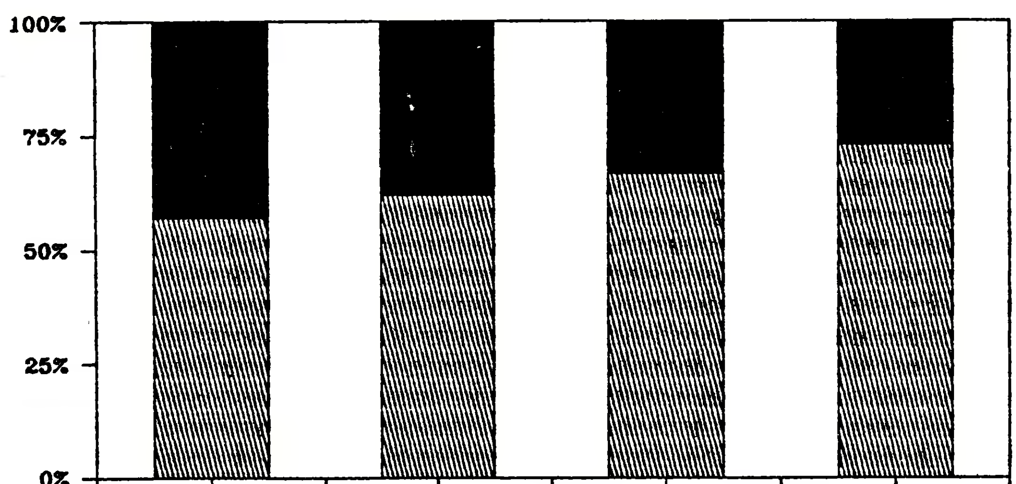


Figure 6.3
The occurrence of degraded sites in the four soil texture classes.



	Sandy Loam	Loam	Sandy Clay Loam	Clay Loam
Total No. of Sites	7	21	3	26
% Degraded	42.9	38.1	33.3	26.9
Degraded (DEG>0)	3	8	1	7
Non-Degraded (DEG<0)	4	13	2	19

Chi-Sq. Test: Not Significant.

Non-Degraded (DEG<0) Degraded (DEG>0)

It may be concluded from the above analyses that the influence of parent material on trail morphology is quite limited, but that there are close relationships between trail compaction and soil properties, especially those indicative of soil texture.

LOCATIONAL FACTORS

Locational factors encompass a range of variables related to elevation, aspect, relief and position on slope. Although elevation has often been reported as a factor of trail degradation (Helgath, 1975; Burde & Renfro, 1986), it is negligible in this study as the altitudes vary little along the study trail.

Aspect

Differences in slope aspect (or direction) may generate a series of physiographic variations, such as soil moisture, soil temperature and vegetation community, which could affect environmental processes. In this study, the aspects of both the trail and terrain were recorded. Trail aspects in azimuths were grouped into eastern-facing (0-180^0) and western-facing (180-360^0) to reflect the predominant direction along the trail.

There was, however, no significant difference in environmental site conditions with respect to the two aspect groups, except for the percent plant litter on tread surface and the soil reaction pH, both of which were higher on the western-facing slopes.

Table 6.7 illustrates the degradation-indicator variables with respect to these two aspect groups. The two compaction-indicator variables had higher values on eastern-facing sample sites, whilst no consistent pattern was found in the trail morphology variables. Nevertheless, the difference in individual variables and summary DEG scores is not statistically significant, either in general or in respect to parent rock.

Overall, only 27% of sites facing eastward were classified as 'degraded' whilst 40% of western-facing sites were in 'degraded' states (Figure 6.4a). No statistical association can be found, however. When stratified by parent rock, a more clear picture was obtained (Figure 6.4b). On that part of Pat Sin Leng underlain by volcanic rock, the proportion of 'degraded' sites on western-facing slopes doubled that on eastern-facing slopes. Such a difference was not found on the western part of the trail where sedimentary rock underlays. The contrasting occurrence of 'degraded' sites on alternate (east/west) slopes of Pat Sin Leng is believed to reflect the use pattern of the trail. As most hikers walk westward from

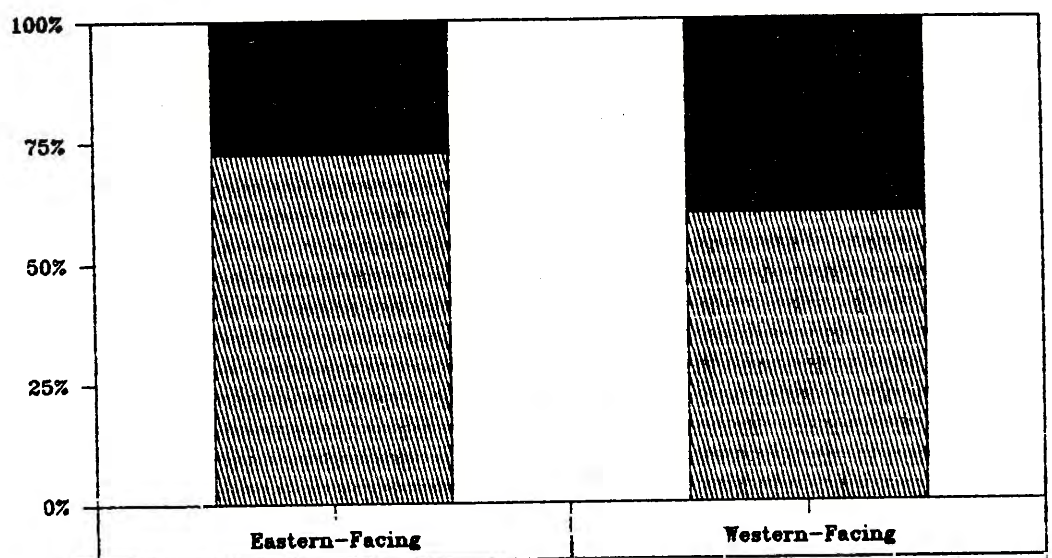
Table 6.7 Comparison of degradation-indicator variables on two aspect groups.

Variable	Aspect Group		Difference[1]		
	E-Facing Sites(n=33)	W-Facing Sites(n=25)	Overall	Volcanic	Sedimentary
ABSCHG	4.14 [2] (0.23)	3.94 (0.31)	ns	ns	ns
PCTCHG	115.02 (7.03)	102.00 (10.11)	ns	ns	ns
BW	86.21 (6.97)	117.67 (7.33)	ns	ns	ns
AID	3.41 (0.55)	3.10 (0.41)	ns	ns	ns
MID	6.69 (0.98)	6.72 (1.04)	ns	ns	ns
TCSA	274.75 (45.34)	410.83 (160.05)	ns	ns	ns
SDDP	1.99 (0.29)	1.92 (0.26)	ns	ns	ns
FMRATIO	79.85 (28.67)	50.81 (8.17)	ns	ns	ns
DEG	-0.12 (0.08)	-0.15 (0.25)	ns	ns	ns

1 Mann-Whitney Test (ns: not significant).
2 Mean value with standard error in bracket.

Figure 6.4
The occurrence of degraded sites in two different aspect groups.

(a) Overall Pattern

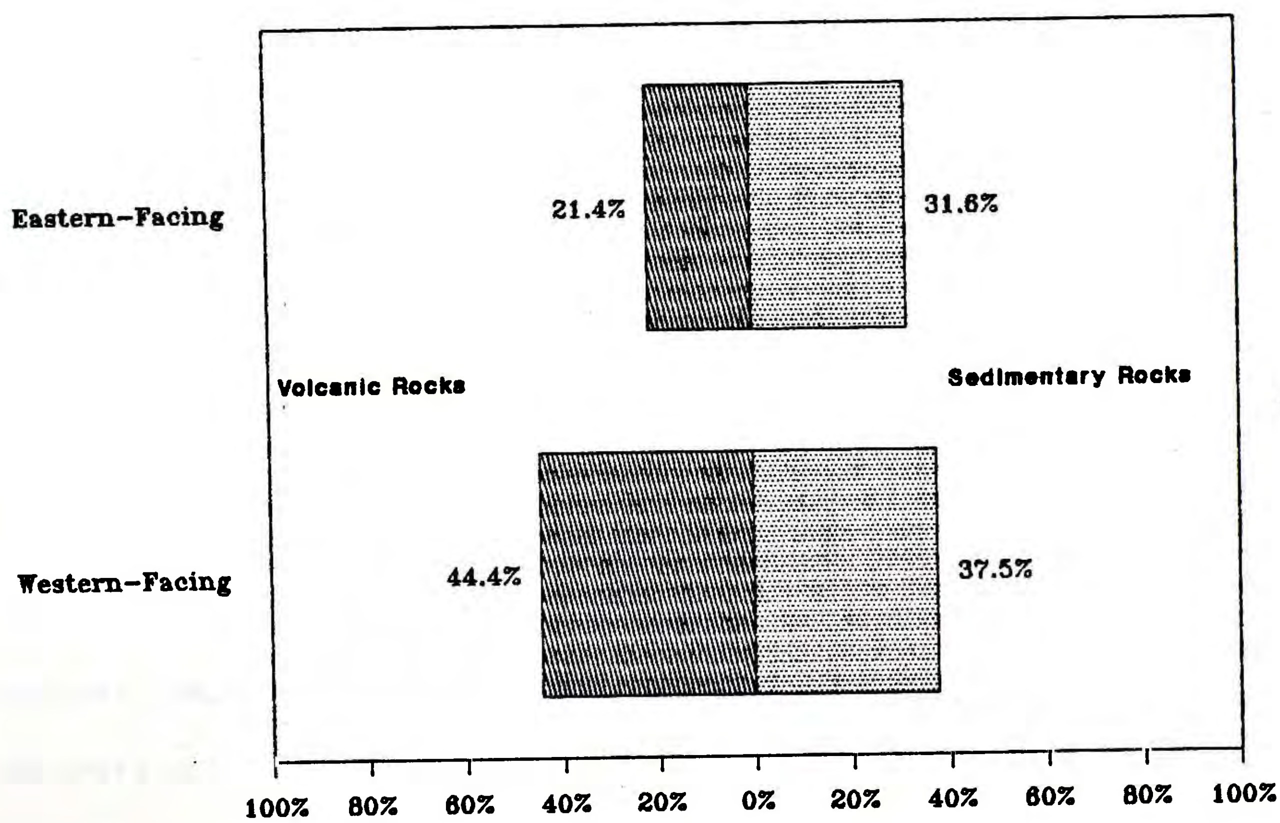


	Eastern-Facing	Western-Facing
Total Sites	33	25
% Degraded	27.3	40
Degraded (DEG>0)	9	10
Non-Degraded (DEG<0)	24	15

Chi-Sq. Test: Not Significant.

Non-Degraded (DEG<0) Degraded (DEG>0)

(b) With Respect to Parent Rock



the trail head at Hsien Ku Fung, eastern-facing slopes were subject mainly to uphill walking whilst the western-facing slopes were subject to downhill walking. This pattern was less evident on the western part of the trail where several major trail junctions are located.

That downslope walking is more damaging than upslope walking has been reported by Bayfield (1973) and Weaver & Dale (1978). Although the difference in individual trail morphological variables is not significant, the cumulative effect may lead to a more apparent contrast in the frequency of 'degraded' sites on the alternate slopes. Further relationships between user-behaviour and trail degradation will be explored in later sections.

Slope Steepness

Slope steepness is an important factor of trail degradation that has frequently been reported. A steep trail is essentially a bare steep slope which is subject to direct raindrop impact. The incised tread surface also acts as a rill or a gully and efficiently channels runoff of high velocity and erosivity.

The importance of slope steepness to trail degradation was clearly identified in this study. There was no conspicuous association between trail slope and soil properties or the composition of the tread surface material, but it exhibited a marked relationship with nearly all degradation-indicator variables, including those related to both trail compaction and morphology. In contrast, other relief variables showed no noticeable relationship with trail degradation (Table 6.8a).

In general, trail slope correlated significantly and positively with tread width, maximum incision, tread cross-sectional area loss, surface roughness (indicated by SDDP), and summary DEG scores. Moreover, trail slope also correlated significantly but inversely with absolute change of penetration resistance (Table 6.8a).

Most of these relationships should be the direct result of increased erosion potential occurring on steep tread surfaces. Maximum incision (tread undercutting), tread cross-sectional area (soil loss) and tread surface roughness belong to this type of relationship.

The positive relationship between trail slope and tread width is more complex and is generally believed to be intermediated by the user behaviour. Indeed, the behaviour of users has been reported as the primary factor of trail widening (Cole, 1991). While the bare width on level or gently sloping paths tends to stabilize after several years of use (More, 1980; Lance et al., 1989; Cole, 1991), this may not be the case on steep trails like that being

Table 6.8 Correlation between relief variables and degradation-indicator variables.

(a) General Relationship

Locational Variable	Degradation-Indicator Variable								
	ABSCHG	PCTCHG	WD	AID	MID	TCSA	SDDP	FMRATIO	DEG
Trail Slope	-0.38**	-0.19	0.49**	0.11	0.37**	0.45**	0.40**	-0.07	0.53**
Terrain Slope	-0.18	-0.17	0.23	0.05	0.12	0.28	0.11	0.10	0.29
Slope-Diff.	0.24	0.06	-0.23	-0.06	-0.23	-0.18	-0.27	0.17	-0.23
Trail-Terrain Angle	0.16	-0.04	-0.19	0.04	-0.19	-0.09	-0.23	0.13	-0.17

Pearson Correlation Coefficient: ** - p<0.01

(b) Trail slope-degradation relationship in different rock types

Parent Rock	Degradation-Indicator Variable							
	ABSCHG	PCTCHG	WD	AID	MID	TCSA	SDDP	FMRATIO
	< normal scale >		<------------ logarithmic scale				------------>	
Volcanic	-0.47**	-0.51**	0.66**	0.48**	0.68**	0.71**	0.67**	0.10
	<---------------------- normal scale						---------------------->	
Sedimentary	-0.21	-0.38	0.14	0.17	0.40*	0.27	0.39*	-0.15

Pearson Correlation Coefficient: * - p<0.05; ** - p<0.01

presently investigated.

The behaviour of hikers on steep surfaces may help explain the wide tread surface on the PSR Trail and the slope-width relationship. Generally, a shorter pace length and the halting action of people walking on sloping surfaces have proven to be more damaging than walking on level surface (Bayfield, 1973; Weaver & Dale, 1978). Moreover, there is evidence indicating that hikers are more likely to wander off the established tread when walking on sloping surface, and this is particularly noticeable when walking downhill (Bayfield, 1973).

The rough terrain of the Pat Sin Range generally discourages hikers from wandering well off the trail, yet the open grassland along the trail corridor permits wandering behaviour on some direct-ascent trail segments.

Examples of lateral spread on two segments on Pat Sin Leng are illustrated by Plates 6.1 & 6.2. It is clearly shown that on steep ground hikers spread laterally (Plate 6.1) and even walk off-trail on the vegetation (Plate 6.2). One of the probable reasons for such behaviour is that when facing the actual and perceived challenge of steepness, the hikers tend to seek safer footing at tread-grass interface or directly on grass. Such behaviour should be particularly evident when walking downhill as the perceived

Plate 6.1 Lateral spread of hikers on the west-facing slope at Hsien Ku Fung (the first crest of Pat Sin Leng from east). Note the spread is mainly on the upper part of the slope.

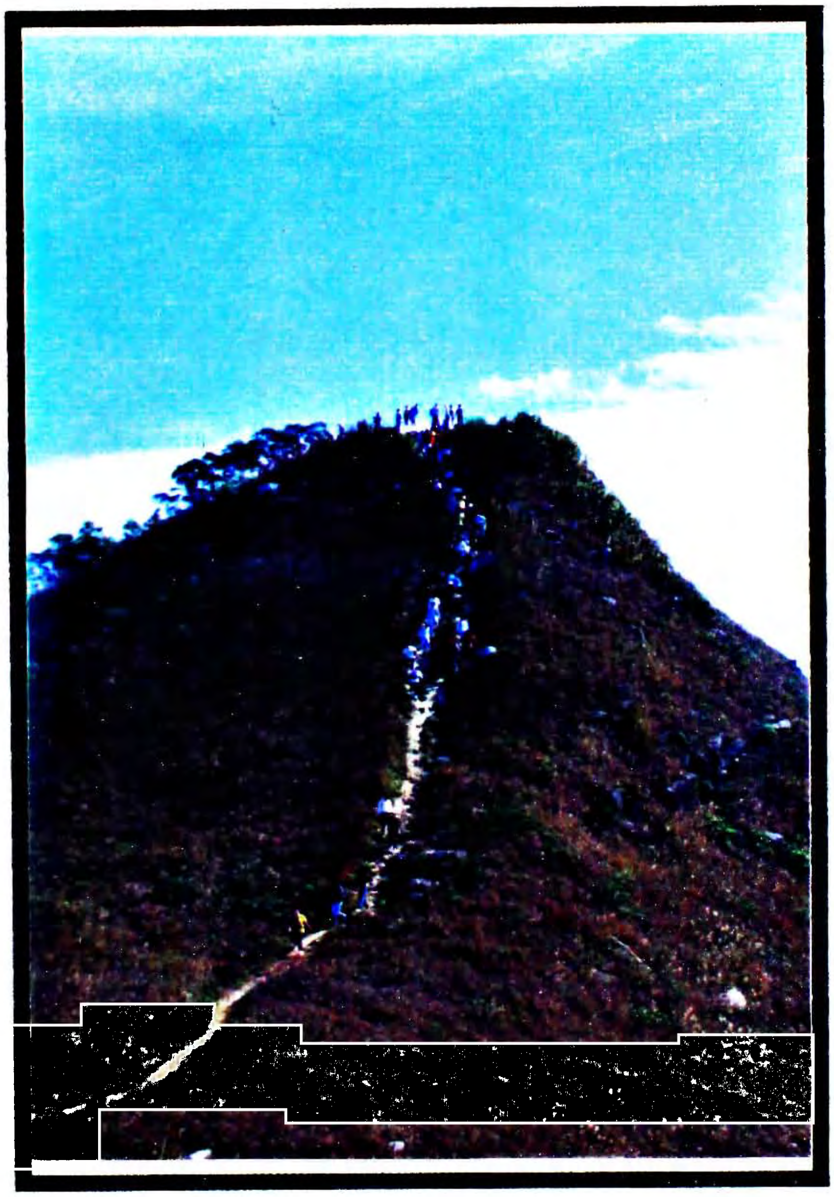


Plate 6.2 An example showing the wandering off-trail of hikers on the west-facing slope at Sheung Tsz Fung (the second crest of Pat Sin Leng from east).

danger of steepness is greater when one looks down from higher ground. This difference may explain the earlier finding that a higher proportion of sites on western-facing slopes along the crests of Pat Sin Leng were classified as 'degraded'.

Another possibility is that when hikers walk on rolling ridges, the unfit ones may take rest on slopes and therefore the others must go around them by wandering. This could also generate wider trail tread on slopes.

With the shear and wear forces of trampling, followed by the alteration of soil structure and the elimination of vegetation (Quinn et al., 1980), the reinforcement of the lateral spread of hikers on steep slopes is liable to enhance the erosional potential of these already susceptible segments.

The nature and strength of the steepness-degradation relationship explored above varies according to parent rock. On the sedimentary rock, the steepness-degradation relationship was insignificant for most indicator variables (with the exceptions of maximum incision depth and tread surface roughness). In contrast, the relationships are strong and exponential on the volcanic rocks (Figure 6.5 a to f).

Figure 6.5

The relationship between trail slope
and trail morphology with respect to parent rock.

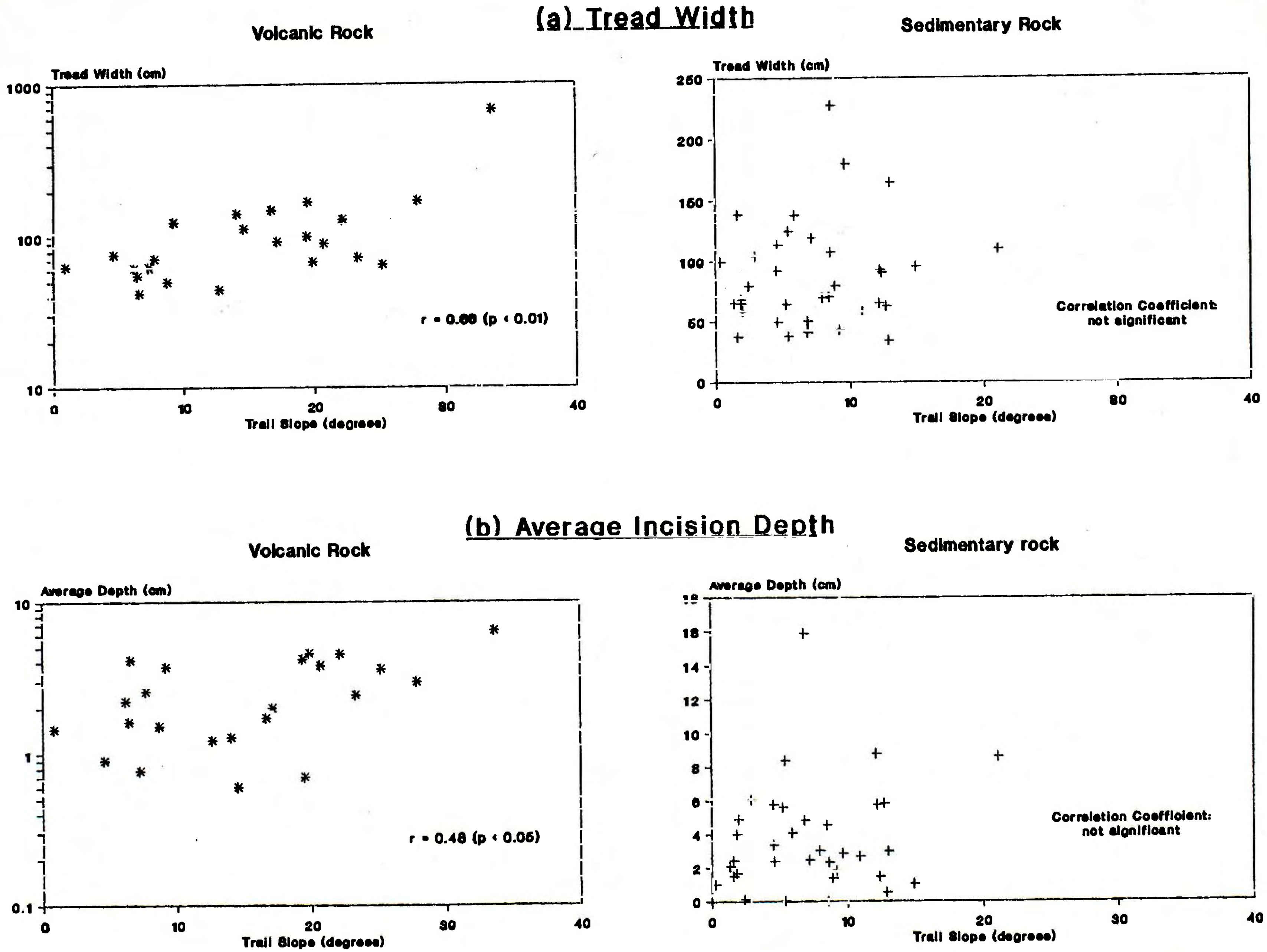
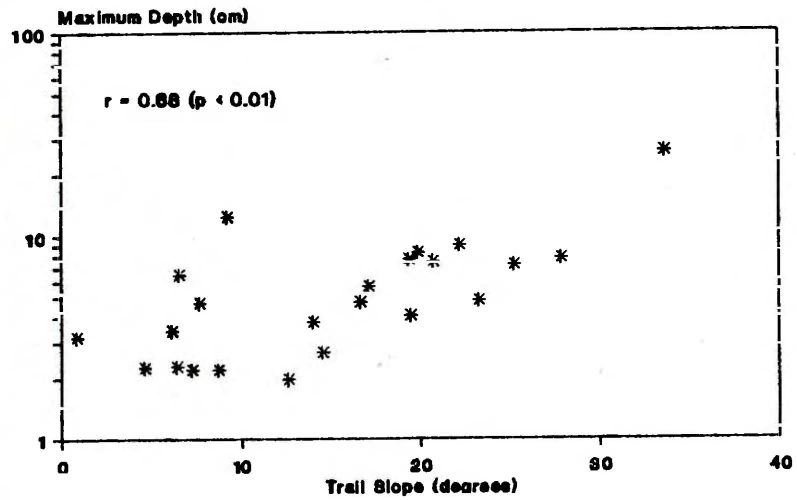


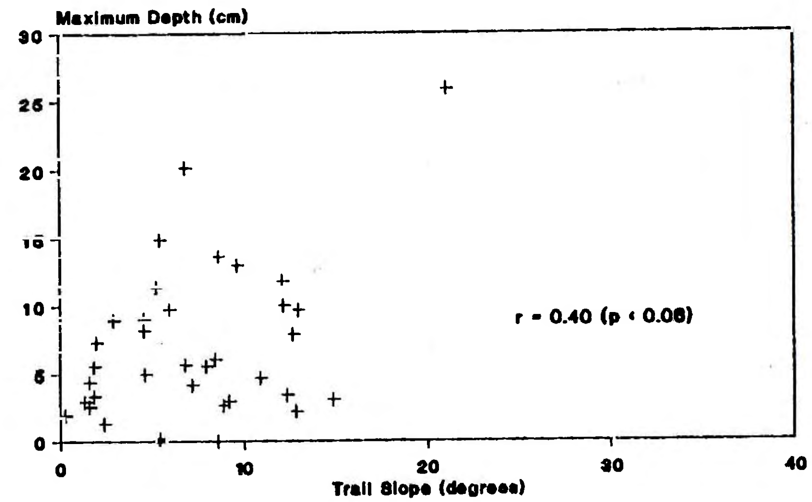
Figure 6.5 (Continued)

(c) Maximum Incision Depth

Volcanic Rock

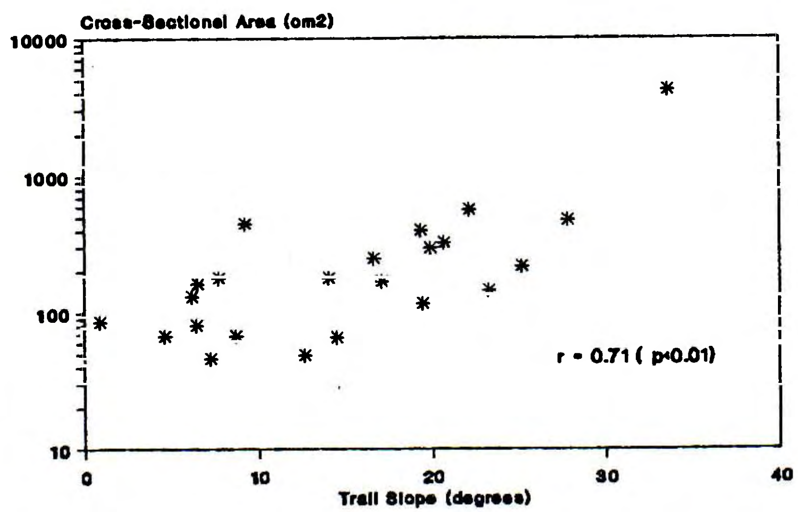


Sedimentary Rock



(d) Tread Cross-Sectional Area

Volcanic Rock



Sedimentary Rock

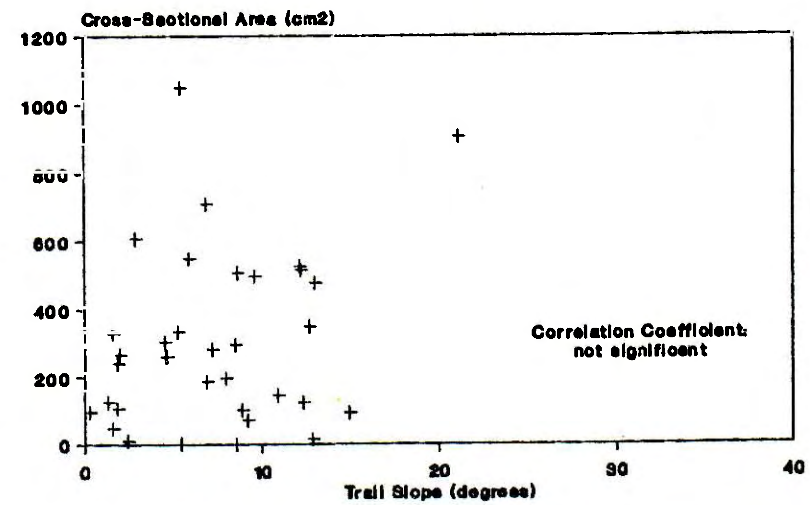
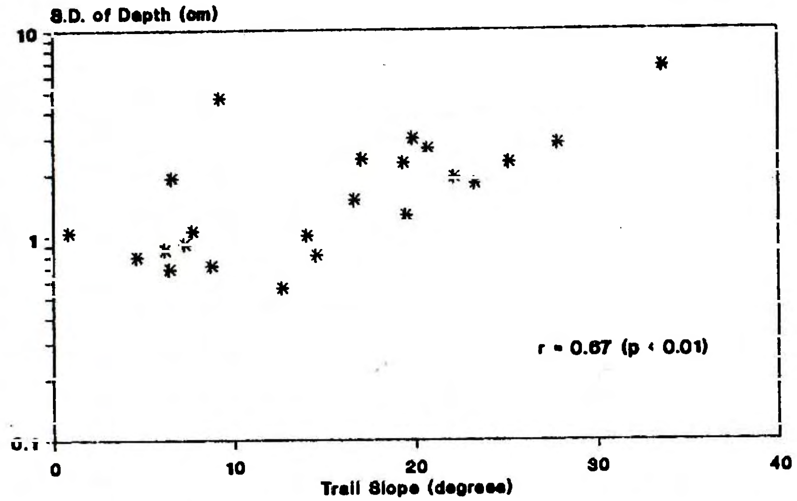


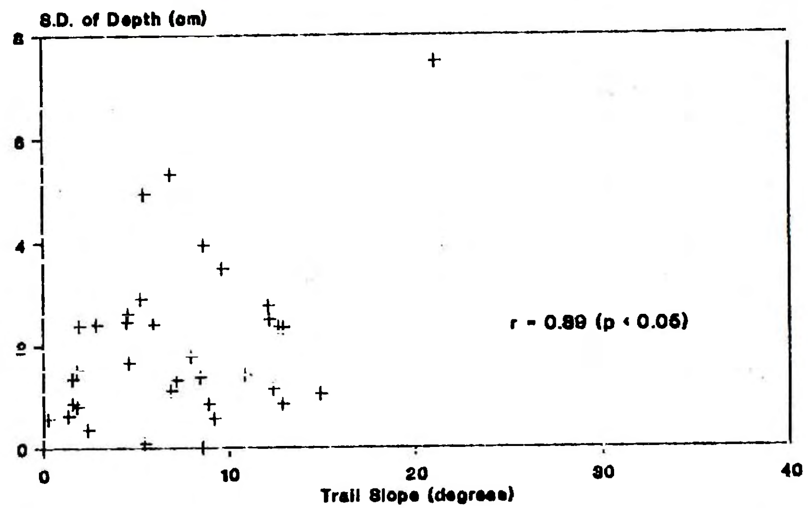
Figure 6.5 (Continued)

(e) Tread Surface Roughness

Volcanic Rock

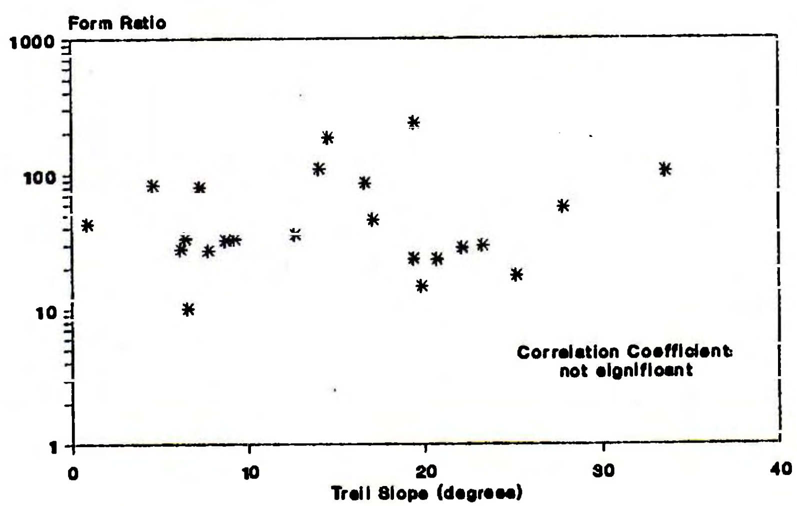


Sedimentary Rock

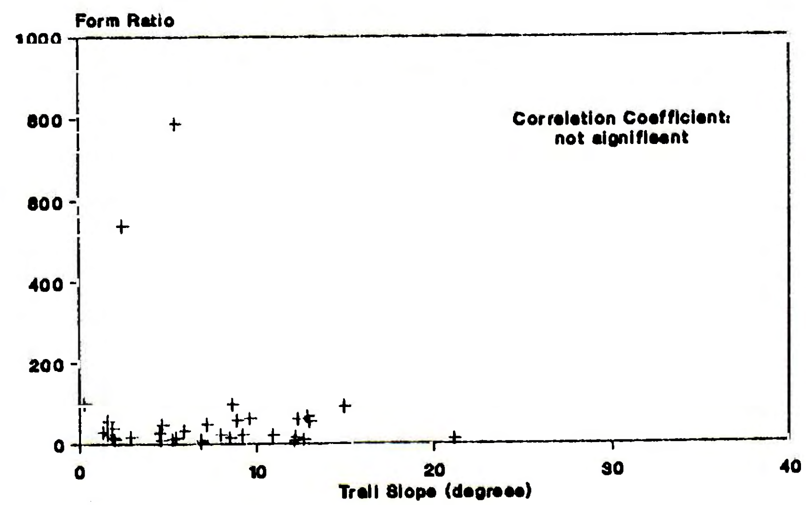


(f) Form Ratio

Volcanic Rock



Sedimentary Rock



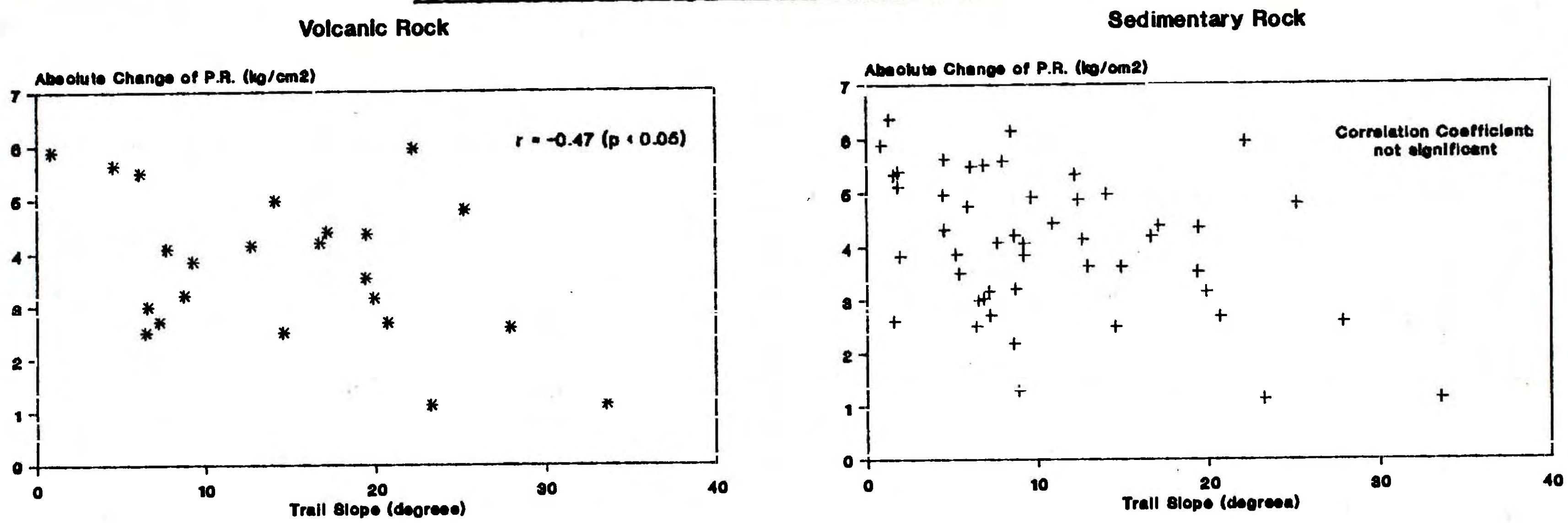
This contrast in response may be partly explained by the inherently higher susceptibility to erosion of the volcanic-derived soil. In addition, the finer-textured and probable moister tread surface when wet (especially after rains) further aggravates the walking condition and promotes wandering behaviour on steep ground. These two specific characteristics on volcanic rock may interact and result in the exponential response of trail degradation to the increase of trail slope. In fact, the exponential relationship between slope steepness and soil erosion by trampling has been reported elsewhere (Quinn et al., 1980).

An inverse relationship between trail slope and compaction was found only in the volcanic rock environments (Figure 6.6 a & b). This indicates that compaction of the tread surface of steeper trail segments is less pronounced than on level ground. This result contradicts to Weaver & Dale's (1978) as they found greater soil compaction on slopes than on level sites. The finding could be accounted for by a fact that steep tread surface is subject to active soil movement downslope, and the concomitant displacement of soil particles may help relieve the soil particles from cumulative compaction at a single point. In addition, the greater shearing force of the human foot on sloping ground help dislodge soil particles (Quinn et al., 1980; Liddle, 1989).

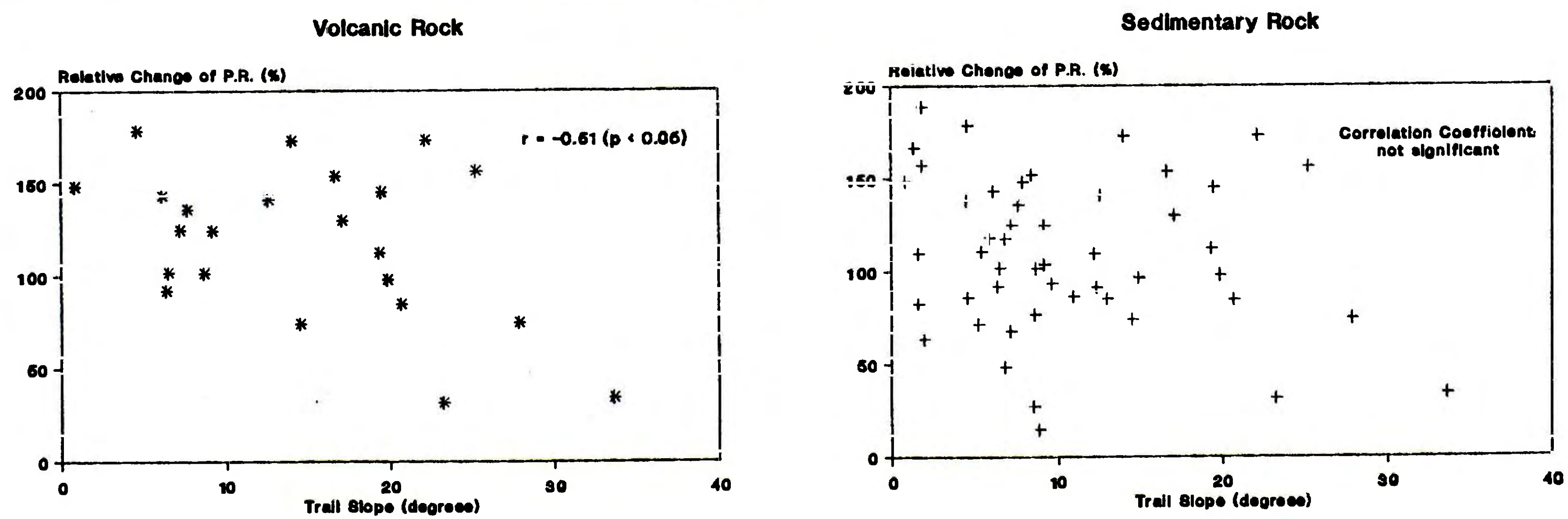
Figure 6.6

The relationship between trail slope and trail compaction with respect to parent rock.

(a) Absolute Change of Penetration Resistance



(b) Relative Change of Penetration Resistance



On the other hand, the positive relationship between trail slope and trail morphology and the inverse relationship between trail slope and compaction suggest that morphological degradation and tread compaction could be two divergent processes and do not necessarily conform to the common theory that erosion is promoted by compaction.

In summary, the increase in the proportion of 'degraded' sites towards the higher trail slope class was clearly shown, but the difference between the 5-12^0 and 12-21^0 classes was not obvious (Figure 6.7a). When the interaction of parent rock is included, the trend of greater proportion of 'degraded' sites on higher slope classes is evident on the both parent rocks (Figure 6.7b).

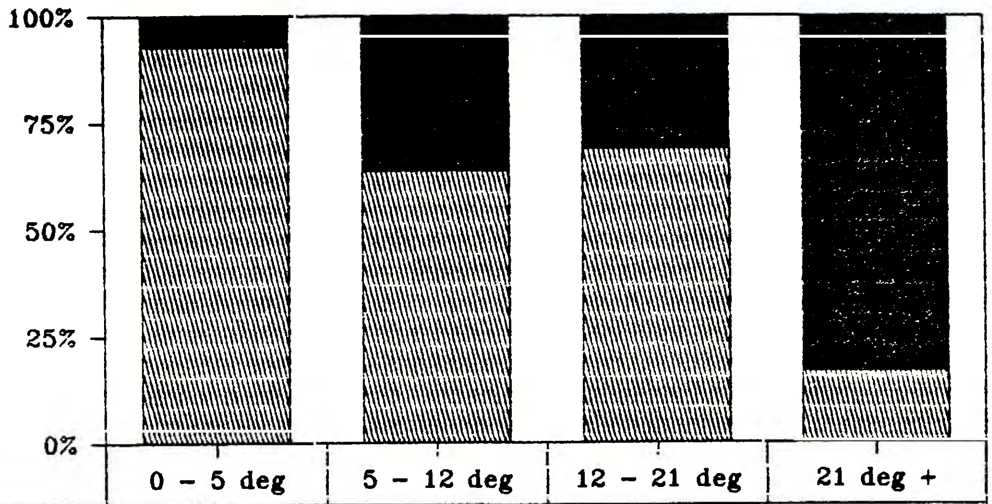
Trail Position on Slope

Trail position on slopes may affect the volume and velocity of water on tread surfaces. It is generally believed that the direct-ascent trail which aligns with the hillslope would be more prone to erosion than the oblique or contour trail which passes across the hillslope.

The results of this study generally confirmed this pattern. The direct-ascent (DA) trails on both upper slope and lower slope segments showed greater morphological degradation than trails in other positions, but variations

Figure 6.7
The occurrence of degraded sites in the four slope classes.

(a) Overall Pattern

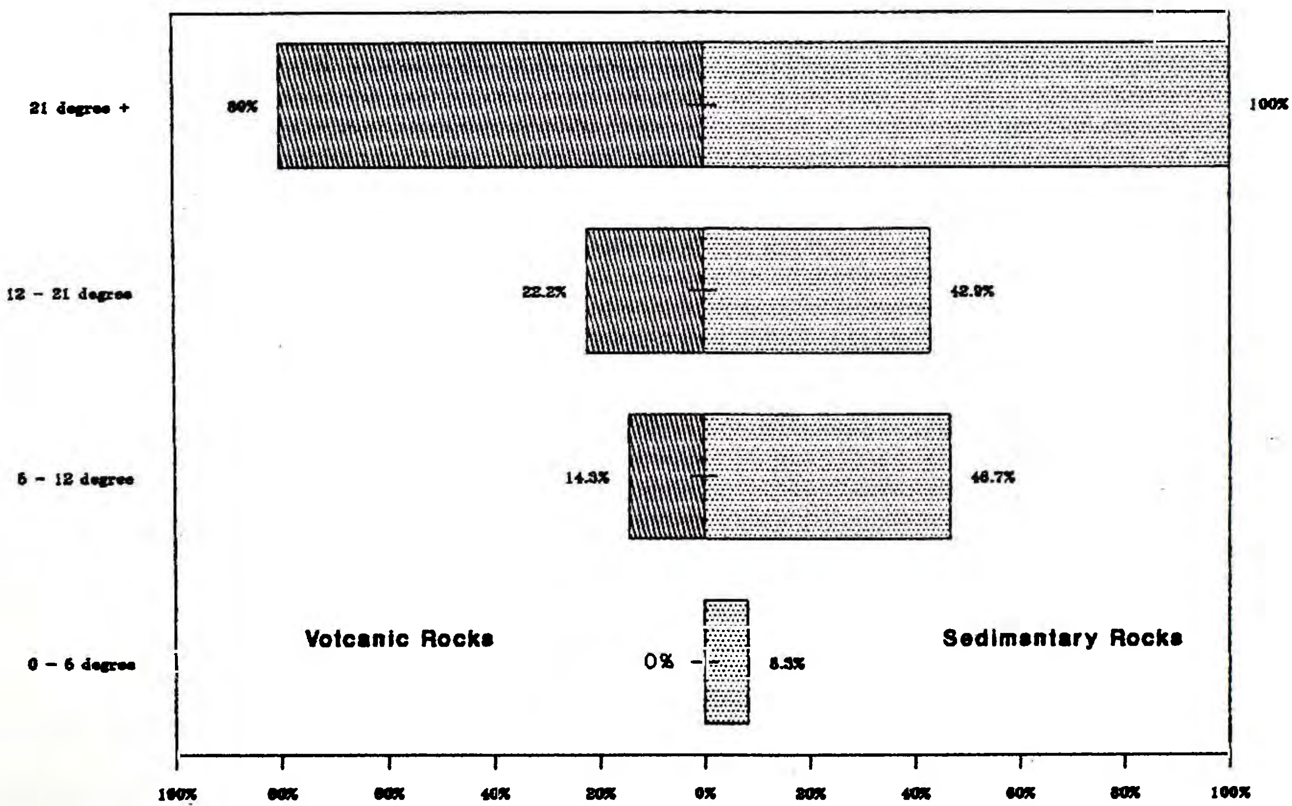


	0 - 5 deg	5 - 12 deg	12 - 21 deg	21 deg +
Total Sites	14	22	16	6
% Degraded	7.1	36.4	31.3	83.3
Degraded (DEG>0)	1	8	5	5
Non-Degraded (DEG<0)	13	14	11	1

Chi-Sq. Test: Prob. < 0.05

Non-Degraded (DEG<0) Degraded (DEG>0)

(b) With Respect to Parent Rock



in the degree of compaction at different positions was not evident (Table 6.9). However, the result of statistical comparisons indicate no significant difference for most variables.

The occurrence of 'degraded' sites was not significantly associated with trail position (Figure 6.8a). However, the occurrence of 'degraded' sites on DA-Interfluve trails merits further comment.

In spite of the direct-ascent nature, only 17.6% of sites on the DA-Interfluve trails were categorized as 'degraded'. This proportion is much lower than those of DA trails situated on upper slope and lower slope segments, and it is even lower than trails on level ground. The finding may be explained partly by the nature of the interfluve on which the runoff tends to diverge out onto alternate catchments at opposite sides. This appears to result in less runoff volume accumulating along the trail.

Apart from the physical reason, the sharp change of slopes at both sides alongside the trail could help confine the hikers within the trail tread.

With regard to parent rock, the occurrence of 'degraded' sites on the volcanic rock exhibited a clear declining trend from 80% of DA-Upper Slope trails to 0% of

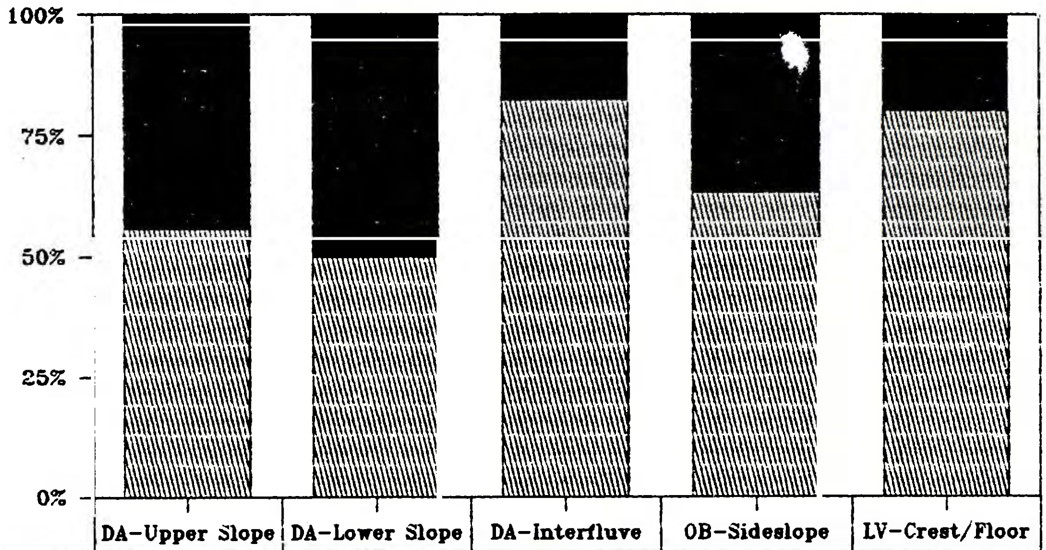
Table 6.9 Comparison of degradation-indicator variables amongst the five different trail positions.

Variable	Trail Position					Difference[1]		
	DA-UppSlp (n=9)	DA-LowSlp (n=8)	DA-Interf (n=17)	OB-Sidehl (n=19)	LV-Cst/Lvl (n=5)	Overall	Volcanic	Sedimentary
ABSCHG	3.21[2] (0.64)	4.11 (0.21)	4.25 (0.29)	4.57 (0.26)	3.12 (0.64)	ns	ns	ns
PCTCHG	80.00 (16.59)	137.77 (8.40)	124.41 (10.26)	105.96 (8.55)	88.16 (21.83)	ns	*	ns
BW	156.24 (65.21)	86.63 (14.35)	98.18 (13.13)	87.60 (8.44)	70.84 (12.49)	ns	ns	ns
AID	3.37 (0.71)	4.07 (1.11)	2.17 (0.29)	4.19 (0.83)	2.14 (0.64)	ns	ns	ns
MID	7.76 (2.43)	9.23 (2.75)	4.93 (0.81)	7.47 (1.15)	3.91 (0.87)	ns	ns	ns
TCSA	670.73 (440.08)	352.50 (102.02)	213.93 (41.46)	328.68 (61.59)	119.87 (26.04)	ns	ns	ns
SDDP	2.39 (0.62)	2.80 (0.81)	1.39 (0.23)	2.09 (0.32)	1.22 (0.26)	ns	ns	ns
FMRATIO	42.49 (11.26)	35.58 (9.28)	100.91 (44.83)	61.90 (27.30)	61.87 (31.91)	ns	ns	ns
DEG	0.66 (0.66)	0.02 (0.19)	-0.21 (0.09)	-0.07 (0.09)	-0.27 (0.11)	ns	*	ns

1 Kruskal-Wallis Oneway ANOVA by Ranks (ns: not significant; * - p<0.05).
2 Mean with standard error in blanket.

Figure 6.8
The occurrence of degraded sites on the five different slope positions.

(a) Overall Pattern

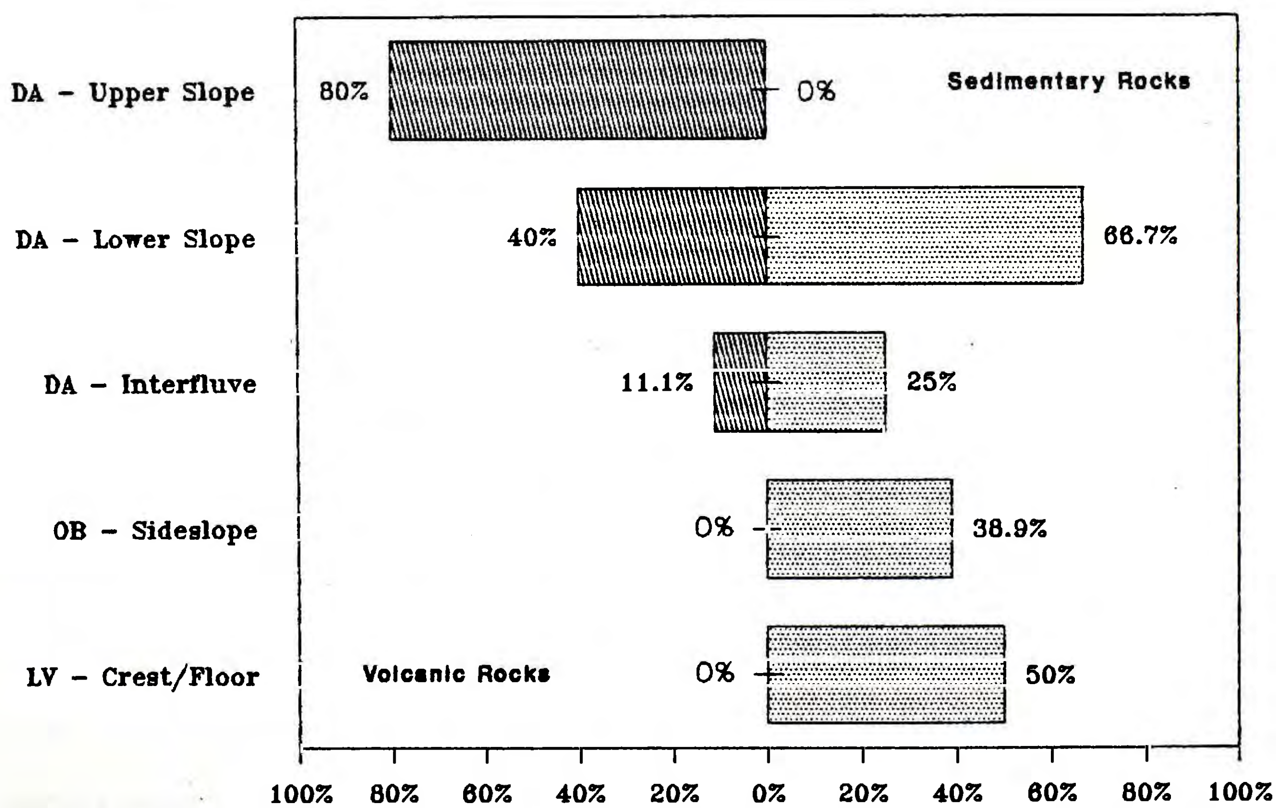


	DA-Upper Slope	DA-Lower Slope	DA-Interfluve	OB-Sideslope	LV-Crest/Floor
Total Sites	9	8	17	19	5
% Degraded	44.4	50	17.6	36.8	20
Degraded (DEG>0)	4	4	3	7	1
Non-Degraded (DEG<0)	5	4	14	12	4

Chi-Sq. Test: Not Significant.

Non-Degraded (DEG<0) Degraded (DEG>0)

(b) With Respect to Parent Rock



LV-Crest/Floor trails (Figure 6.8b). In contrast, all the 4 DA-Upper Slope sites on sedimentary rock were 'non-degraded'. Other positions on sedimentary rocks had varied occurrence of 'degraded' sites.

This finding demonstrates the acute trail degradation problem occurring on the upper slopes on the volcanic rock in the PSR Trail. Such a pattern is more obvious on the western-facing slopes (Plate 6.3).

To further illustrate this phenomenon, the third crest of Pat Sin Leng - Choi Wo Fung (the crest in Plate 6.3) was remeasured for trail slope, tread width and maximum incision depth on both east and west slopes at 5-m interval (Figure 6.9). The highest values of trail slope, tread width and maximum incision coincided with the upper part of the west-facing slope. Except for the maximum incision depth, such patterns do not exist on east-facing slopes. Three probable reasons may explain this phenomenon.

As mentioned earlier, the perceived challenge of average hikers walking downhill may be greater. It is perhaps even stronger when hikers view downwards from the crest through a convex slope (Plate 6.4). Such perceptions are liable to promote wandering behaviour amongst hikers as mentioned earlier (Refer to Plate 6.1). It could thus

Plate 6.3 Trail degradation on the upper slope positions of the west-facing slopes at Pat Sin Leng. Note the wide bare width and the developing multiple treads alongside.

Figure 6.9

Change of slope, width and incision of the trail on the alternate slopes of Choi Wo Fung (at Pat Sin Leng).

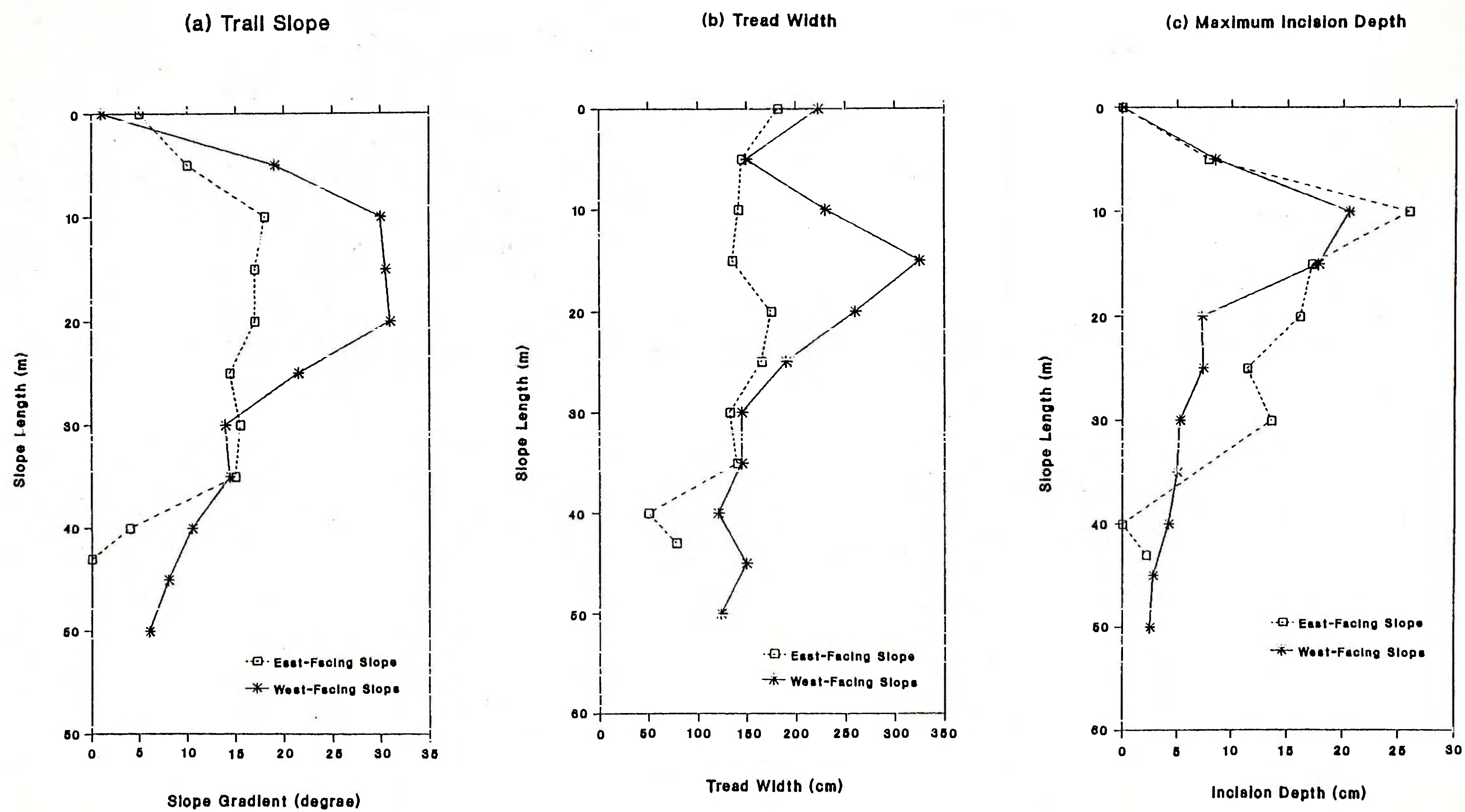
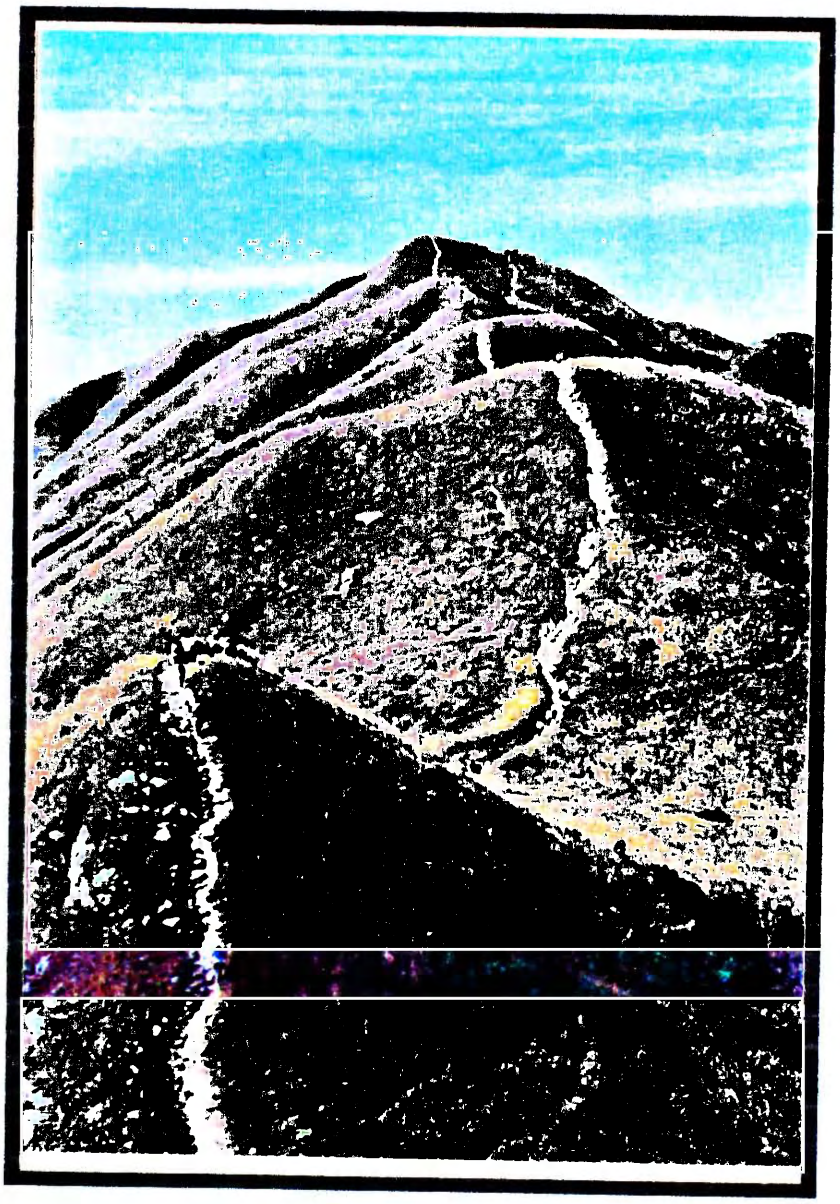


Plate 6.4 The hikers standing on the third crest of Pat Sin Leng (Choi Wo Fung). The perceived challenge could be much greater as viewed downward high from the crest.



explain the wider tread width on the upslope positions.

In addition, it has also been reported that the erosion rate on convex shape of slopes, which is the dominant form of upper slopes, is greater than that on uniform and concave slopes (Young, 1969). The coexistence of vulnerable slope shape and an ever-expanding bare tread on the upper slopes together encourages greater degradation at this position.

Whilst Summer (1980) and Cole (1987) have recommended that trails located high on slopes have smaller watersheds and less erosion potential than trails close to the base of slopes, the above finding indicates that this recommendation is not necessarily applicable to trails of the direct-ascent type.

OVERALL EVALUATION

To summarize the relationship between environmental factors and degradation-indicator variables, multiple stepwise regression was undertaken. The results are shown as Table 6.10 for trail compaction variables and Table 6.11 for trail morphology variables.

The analyses for absolute and relative penetrability changes show that soil properties such as sand and silt

Table 6.10 The results of multiple regression analyses for the compaction-indicator variables.

Independent Variable	Dependent Variable: ABSCHG	PCTCHG
Trail Slope (deg.)	F=8.20** b=-0.05	
BW (cm)		F=6.06** b=-0.14
Sand (%)	F=6.70** b=0.08	
Org.Mat.(%)	F=6.77** b=1.14	F=5.95* b=28.63
Silt (%)		F=5.29** b=-3.21
Constant	b=2.72	b=195.32
R Square	0.27	0.25

F is the F value and b is the unstandardized regression coefficient.
* - $p<0.05$; ** - $p<0.01$

Table 6.11 The results of multiple regression analyses for the trail morphology variables.

Independent Variable	BW	AID	MID	TCSA	SDDP	FMRATIO	DEG
Trail Slope (deg.)	F=17.77** b=5.75		F=9.04** b=0.36	F=14.37** b=34.09	F=10.37** b=0.10		F=22.24** b=0.06
Silt (%)		F=6.60* b=0.22					
Clay (%)			F=10.21** b=-0.31				
Constant	b=40.49	b=-3.49	b=10.95	b=-18.17	b=2.73		b=-0.65
R Square	0.24	0.11	0.27	0.20	0.24		0.28

F is the F value and b is the unstandardized regression coefficient.
* - $p<0.05$; ** - $p<0.01$

content and organic matter content are significant components in the regression models, indicating their importance in affecting compaction on the study trail. Other associations include that of the absolute change of penetration resistance and trail slope and that of the relative change of penetration resistance with tread width.

As expected, trail slope is the single most useful predictor of tread width, maximum incision, tread cross-sectional area loss, surface roughness, and the summary degradation score along the study trail. The degradation-indicator variables show no discernible association with other environmental site characteristics. The only exception is trail incision. As shown in Table 6.11, average trail incision is not related to trail slope, but related positively to the percentage of silt. Moreover, the maximum incision depth is not merely associated with trail slope, but also relates inversely with the percentage clay. This indicates that trail incision is also controlled by soil characteristics in addition to merely slope steepness.

The form ratio shows no discernible association with any other variable. Moreover, no significant regression model can be identified for the form ratio, indicating that the tread shape may not be related to environmental factors.

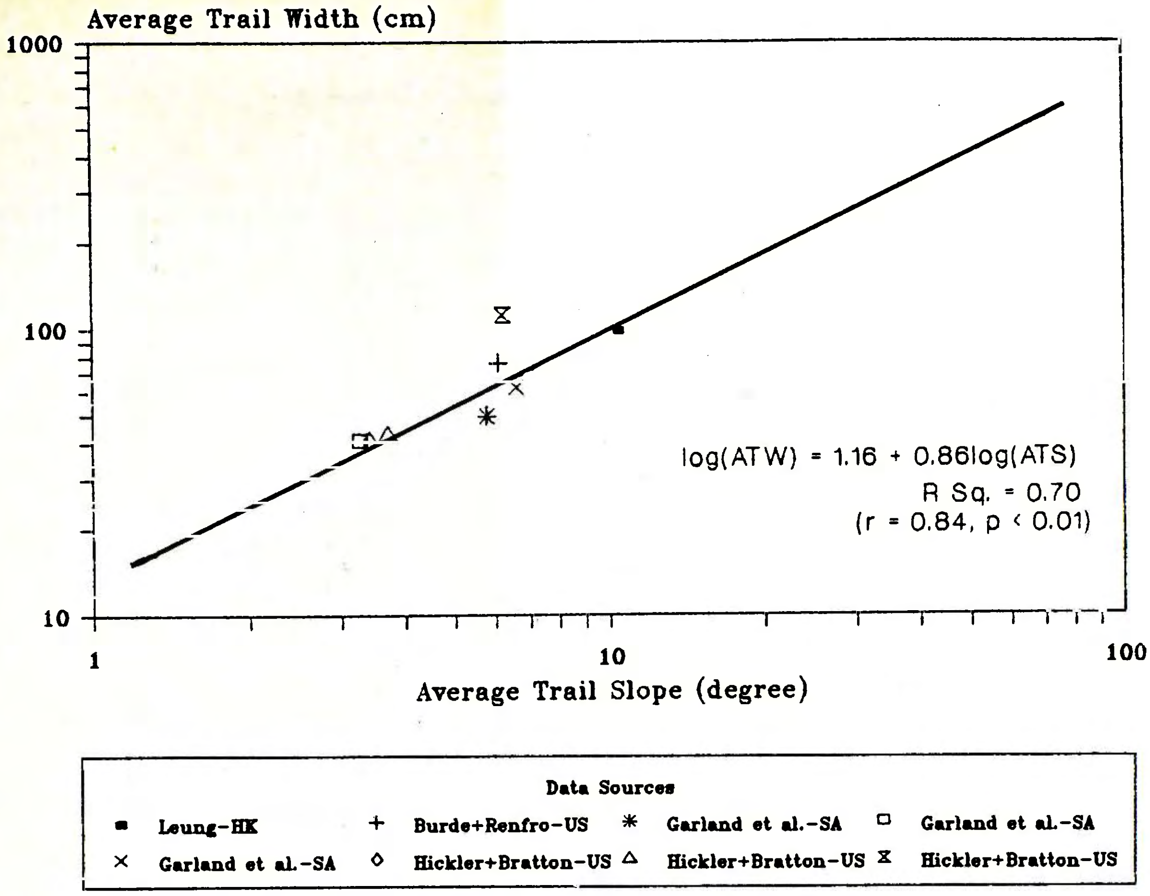
Regression analysis was also undertaken on data reported from previous studies and the results of this research so as to better understand the general slope-degradation relationship. Although there were only limited data, obtained from varying environments, and by varying measuring techniques, a rough picture could still be shown.

The double-log relationship between average trail slope and average trail width achieved a considerably high level of R^2 of 0.7 (Figure 6.10 a). The exponential relationship between average trail slope and average trail cross-sectional area gained a higher R^2 of 0.73 (Figure 6.10 b). This results, as well as the findings presented earlier in this chapter, suggest that trail slope is the underlying factor of trail degradation and that the relationship between trail slope and degradation is generally linear, though it can be exponential in susceptible areas. However, there is no significant relationship between trail slope and average incision depth (Figure 6.10 c), indicating that the average level of incision occurs on trail treads may be an exception of the slope-degradation relationship. Rather, other site characteristics, such as soil properties, may be more important in controlling the average incision.

Figure 6.10

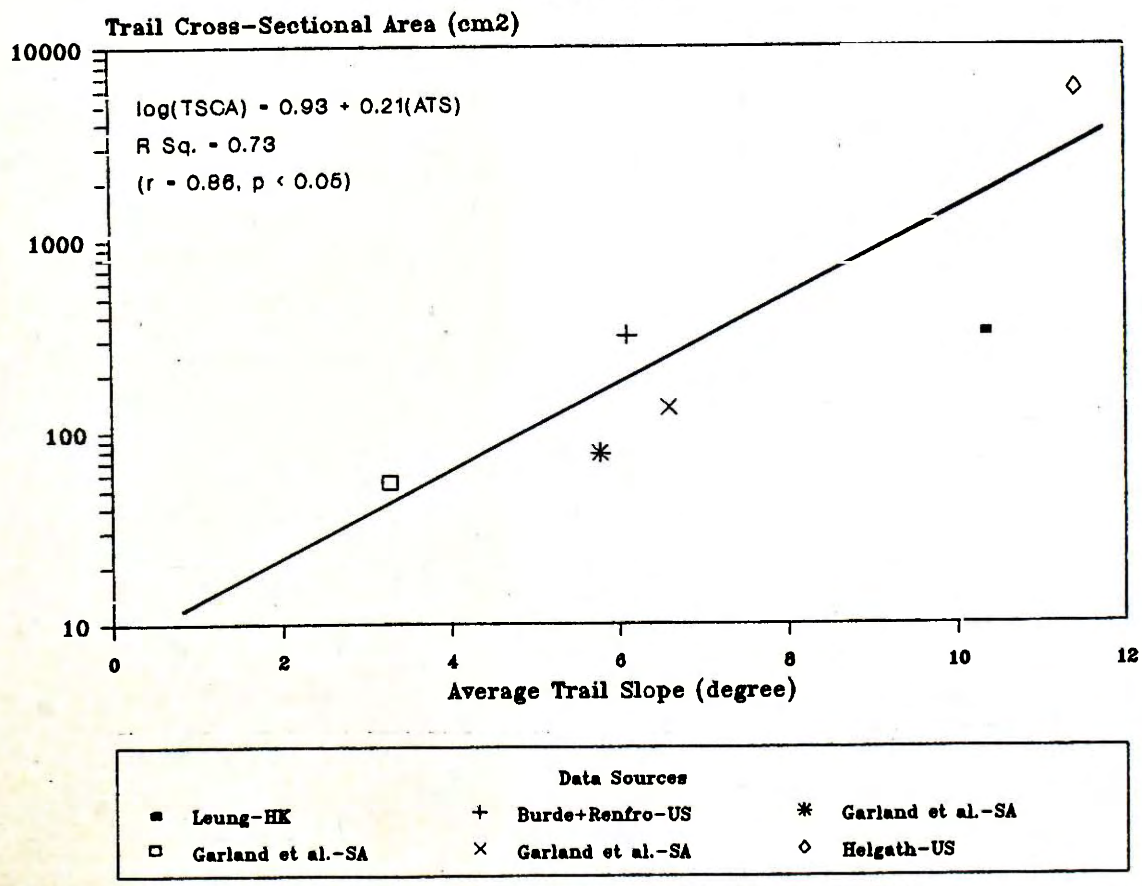
Regression models of the published data
showing the trail slope-degradation relationships

(a) Trail Slope and Width



Location of the studies: HK-Hong Kong; US-U.S.A.; SA-South Africa.

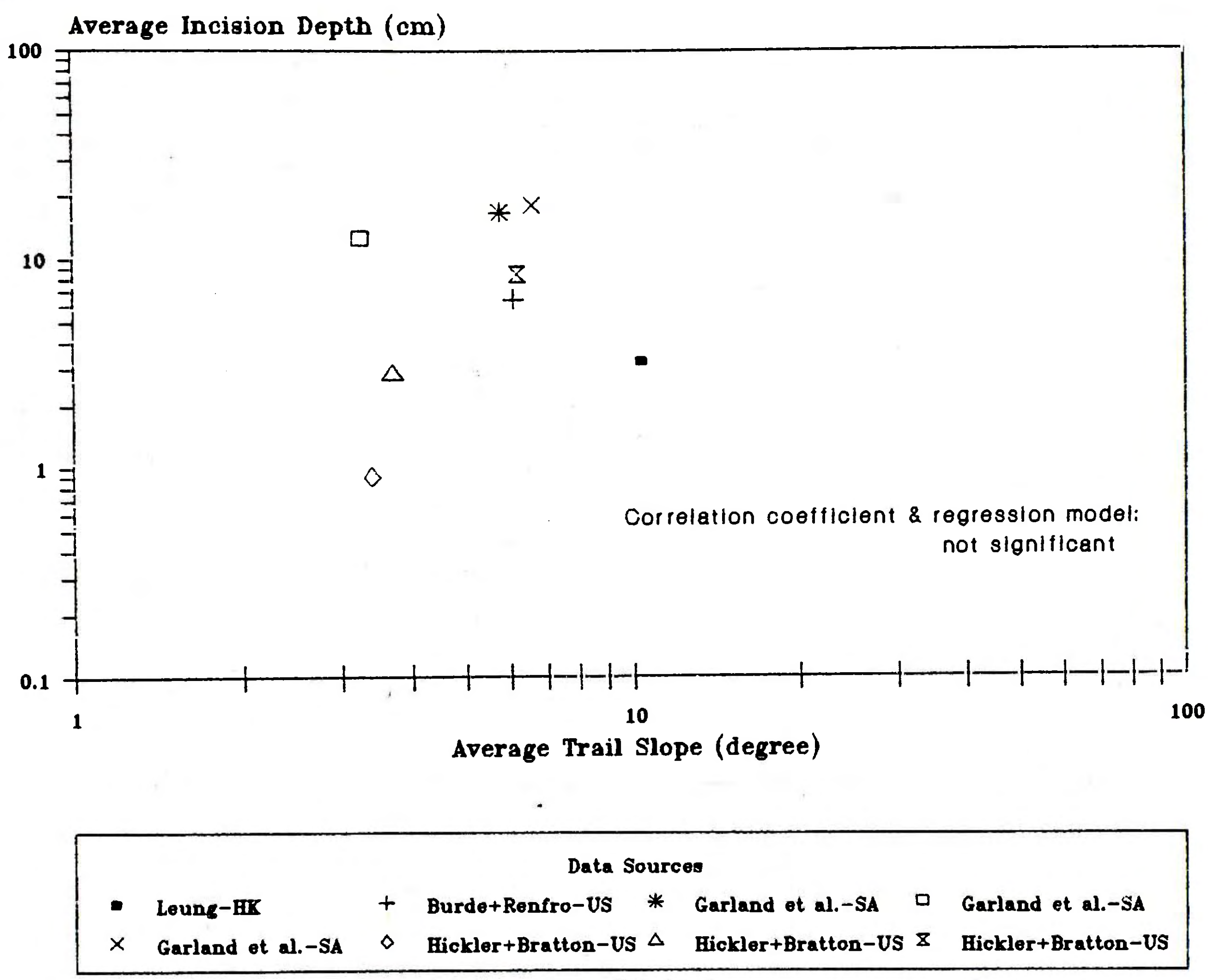
(b) Trail Slope and Cross-Sectional Area



Location of the studies: HK-Hong Kong; US-U.S.A.; SA- South Africa

Figure 6.10 (continued)

(c) Trail Slope and Incision



Location of the studies: HK-Hong Kong; US-U.S.A.; SA-South Africa.

CHAPTER VII

MANAGEMENT IMPLICATIONS

INTRODUCTION

Trail management is an integral part of outdoor recreation management. It is especially important in the natural settings of country and national parks which aim to protect the landscape and biotic resources in addition to providing recreation opportunities. The proliferation of degraded trails, whether in forms of wide bare scars, deeply-incised treads, multiple treads or impromptu trails in a park's environment clearly undermine both conservation and recreation goals.

In order to effectively and efficiently tackle the trail degradation problem, park managers need objective information on the status, causes, factors and processes of degradation occurring in parks. They also need to know how trail degradation may affect the quality of both the environment and the recreation experience. Whilst the present study does not address all these issues, it is hoped that the findings of this study may throw light on the better management of local trails and on the local practice of trail management.

MANAGEMENT CONSIDERATIONS

The foremost question under consideration should be the goal of trail management. At present, safety and convenience of hikers are the overwhelming concerns of park management in Hong Kong. Managing trails for conservation and for better recreational experience seem to be overlooked. It is the author's opinion that they should be of equal importance in country parks with unique conservation and recreational value.

Owing to the limited park resources and heavy recreational demand in Hong Kong, limiting their use or constructing more trails appears to be futile. Rather, the key strategy for local trail management is to concentrate users on existing trail treads on one hand, and to increase the durability of the trail network on the other.

Local trail maintenance has too often relied on engineering solutions. Paving trail treads with asphalt and rock slabs, constructing steps and water drainage are examples of the conventional management response to site degradation in Hong Kong. While these measures are capable of increasing durability *in situ*, the high cost, unending maintenance input and often obtrusiveness may not justify their wider application. For trail segments situated on vulnerable locations, relocation seems to be the enduring solution and should be carefully considered in addition to engineering measures.

THE CASE OF PAT SIN RANGE TRAIL

The results of this study suggest that the Pat Sin Range Trail, or at least that portion under study, was generally in good condition, yet severely degraded sites did exist at several locations. Similar degraded sites can also be found on other trails within the Pat Sin Leng Country Park.

These results have immediate management implications. Particular concern should be paid to trail segments of the direct-ascent type and with steep slopes of more than about 20^0. As the degradation response of trails on the volcanic rocks (or volcanic trails) was more pronounced than on the sedimentary rocks, priority in management should be given to the former. The upper part of such slopes should be carefully maintained in such a way that the hikers will find a safe footing on the tread and not wander off. Placing rock slabs may be one of the solutions.

As a corollary, inappropriate location of trails in a volcanic environment without adequate considerations of slope type and steepness is conducive to degradation. Such degraded trails are costly to repair.

To minimize the severity of degradation, regardless of parent rock, trails should be aligned obliquely or perpendicularly at sidehill locations or along interfluves (e.g. shoulder of hills) wherever possible.

Table 7.1 attempts to summarize the problems of trail degradation along the PSR Trail. Corresponding management strategies for each type of degradation are recommended.

Table 7.1 Forces, causes and recommended management strategies for different types of trail degradation identified in the present study.

Type of Degradation	Impact Force	Probable Cause	Type of Hiker Actions[1]	Management Recommendation
(1) Tread Compaction	trampling	walking	unavoidable	confine impact on tread
(2) Tread Widening				
General	trampling	walking abreast/ wandering off-trail	uninformed/careless unskilled	education/ interpretation
On Slope	trampling	lateral spread on steep slope	unavoidable	relocate to durable site
(3) Tread Incision	waterflow	steep slope	unavoidable	improve drainage/ relocate to durable site
(4) Tread Erosion	waterflow + trampling	steep slope	unavoidable	improve drainage/ relocate to durable site
(5) Multiple Treads	trampling	wandering off-trail/poor original tread	careless/unskilled unavoidable	education/ interpretation/ harden site
(6) Shortcuts/ Impromptu Trails	trampling	seeking for easier route	careless/unskilled	education/ interpretation

[1] Typology refer to Lucas (1990)

Trampling and water are the predominant forces of trail degradation in general. The relative importance of each cause varies amongst the different types of degradation, but lateral spread of hikers on tread and steep slopes seem to be the root of many types of problems.

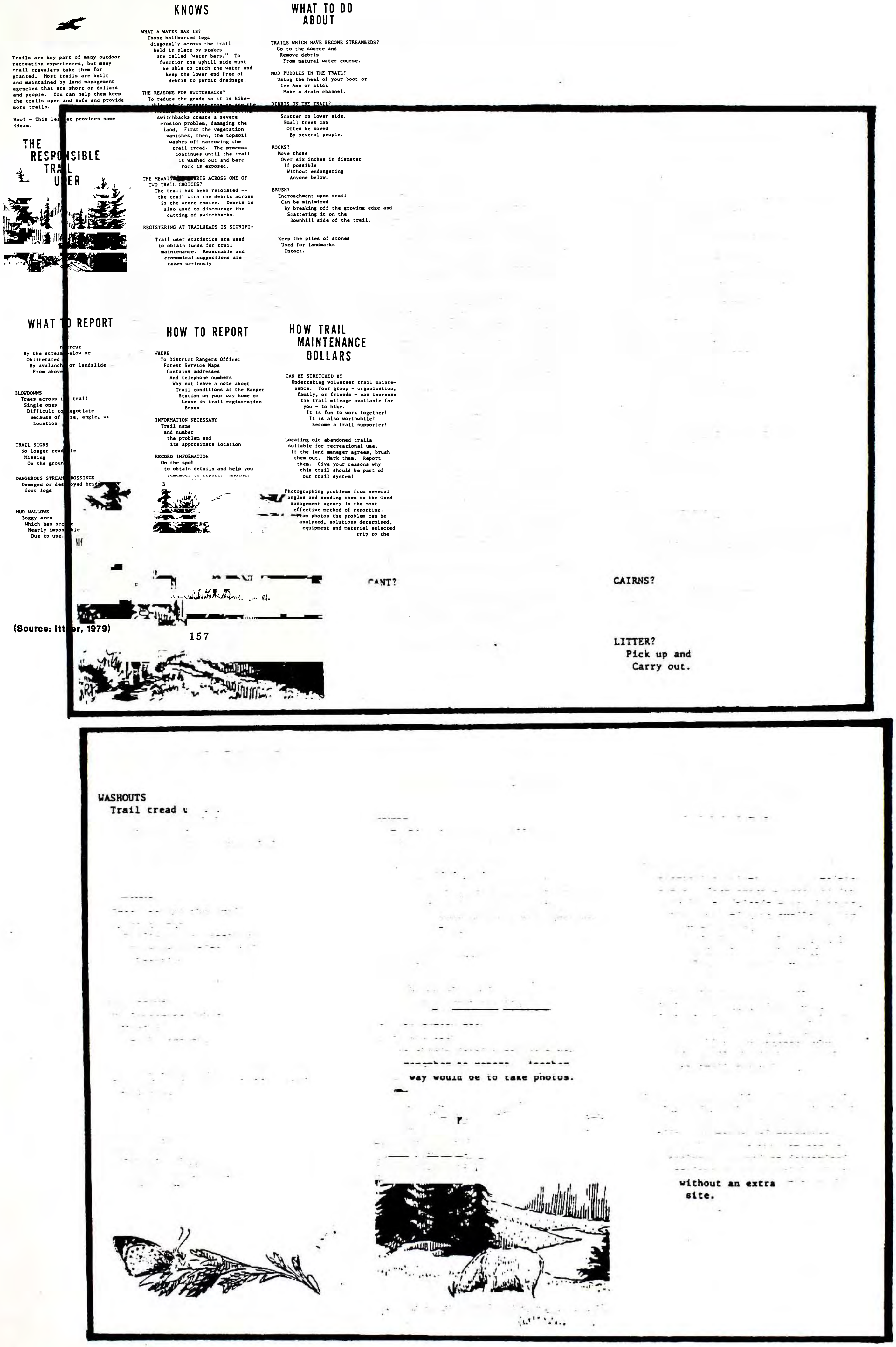
Although a number of degradation types seem to be unavoidable, it should be noted that careless (or thoughtless), unskilled or uninformed actions of hikers (Lucas, 1990) contribute significantly to trail degradation. Therefore, manipulating the behaviour of users appears to be an important and immediate step for avoiding unnecessary impacts on trails.

Education, interpretation and information are the major means for attaining this goal. Knowledge about trail and the responsibility of trail user, and the practice of low-impact trail use should be included. At present, a low-impact practice of recreation is only implicitly stated in the 'Country Code', and the foci are on hill fires and littering (Government Information Services, 1990). A more specific 'hiking code' is communicated within some hiking groups (Chu, 1991), but the limited circulation does not reach the average hiker who frequently walks abreast and who carelessly takes shortcuts or wanders from trails.

In North America, the idea of low-impact trail use has been advocated through publications (Ittner, 1979), the mass media (Gebler, 1979) and campaigns (Matheny, 1979). An example is shown in Figure 7.1 which was published and circulated by the U.S. Forest Service. This leaflet not only tells the hiker what they should do when travelling in natural areas, but more importantly it disseminates knowledge of the trail and provides information on how hikers can help maintain the quality of trail resources. This kind of information is thought to be more constructive than merely a few words of code.

On the other hand, a sense of responsibility can also be developed through the involvement of the public in trail planning, management and maintenance consideration of trail resources. Alignments and routing of new trails can be discussed with concerned organizations and citizens. Maintaining a long mileage of trails can be facilitated by the help of hikers. At present, public participation can be seen in the Voluntary Work Programme and the Hiking Litter Wardens Scheme (Agriculture & Fisheries Department, 1991). Such programmes could be expanded to cover the problem of trail degradation. Certain types of trail degradation, such as tread widening on slopes, incision and the erosion of trails, are either the direct result of slope steepness or the consequences of the unavoidable response of hikers on sloping ground. Under these circumstances, a different series of management strategies

Figure 7.1
A leaflet from the U.S. Forest Service
that advocates responsible trail use.



Trails are key part of many outdoor recreation experiences, but many trail travelers take them for granted. Most trails are built and maintained by land management agencies that are short on dollars and people. You can help them keep the trails open and safe and provide more trails.

How? - This lea[illegible]et provides some ideas.

THE RESPO[illegible]SIBLE TRA[illegible]L U[illegible]ER

KNOWS

WHAT A WATER BAR IS?
Those halfburied logs diagonally across the trail held in place by stakes are called "water bars." To function the uphill side must be able to catch the water and keep the lower end free of debris to permit drainage.

THE REASONS FOR SWITCHBACKS?
To reduce the grade so it is hike- [illegible] switchbacks create a severe erosion problem, damaging the land, First the vegetation vanishes, then, the topsoil washes off narrowing the trail tread. The process continues until the trail is washed out and bare rock is exposed.

THE MEANIN[illegible]BRIS ACROSS ONE OF TWO TRAIL CHOICES?
The trail has been relocated -- the trail with the debris across is the wrong choice. Debris is also used to discourage the cutting of switchbacks.

REGISTERING AT TRAILHEADS IS SIGNIFI-

Trail user statistics are used to obtain funds for trail maintenance. Reasonable and economical suggestions are taken seriously

WHAT TO DO ABOUT

TRAILS WHICH HAVE BECOME STREAMBEDS?
Go to the source and Remove debris From natural water course.

MUD PUDDLES IN THE TRAIL?
Using the heel of your boot or Ice Axe or stick Make a drain channel.

DEBRIS ON THE TRAIL?
[illegible] Scatter on lower side. Small trees can Often be moved By several people.

ROCKS?
Move those Over six inches in diameter If possible Without endangering Anyone below.

BRUSH?
Encroachment upon trail Can be minimized By breaking off the growing edge and Scattering it on the Downhill side of the trail.

CAIRNS?
Keep the piles of stones Used for landmarks Intact.

LITTER?
Pick up and Carry out.

WHAT T[illegible] REPORT

WASHOUTS
Trail tread u[illegible] [illegible]rcut By the stream [illegible]elow or Obliterated By avalanch[illegible] or landslide From above

BLOWDOWNS
Trees across t[illegible] trail Single ones Difficult to [illegible]egotiate Because of [illegible]ze, angle, or Location

TRAIL SIGNS
No longer read[illegible]le Missing On the groun[illegible]

DANGEROUS STREAM [illegible]ROSSINGS
Damaged or des[illegible]oyed brid[illegible] foot logs

MUD WALLOWS
Boggy ares Which has bec[illegible]e Nearly impos[illegible]ble Due to use.

HOW TO REPORT

WHERE
To District Rangers Office: Forest Service Maps Contains addresses And telephone numbers Why not leave a note about Trail conditions at the Ranger Station on your way home or Leave in trail registration Boxes

INFORMATION NECESSARY
Trail name and number the problem and its approximate location

RECORD INFORMATION
On the spot to obtain details and help you [illegible] way would be to take photos.

HOW TRAIL MAINTENANCE DOLLARS

CAN BE STRETCHED BY
Undertaking volunteer trail maintenance. Your group - organization, family, or friends - can increase the trail mileage available for you - to hike. It is fun to work together! It is also worthwhile! Become a trail supporter!

Locating old abandoned traila suitable for recreational uae. If the land manager agrees, brush them out. Mark them. Report them. Give your reasons why this trail should be part of our trail system!

Photographing problems from several angles and sending them to the land management agency is the most effective method of reporting. From photos the problem can be analyzed, solutions determined, equipment and material selected [illegible] trip to the site. [illegible] without an extra

CANT?

(Source: Itt[illegible]er, 1979)

should be utilized.

Engineering solutions have traditionally been sought for most of these problems. Indeed, wood and rock slabs, waterbars and drainage ditches can be seen on both ends of the Pat Sin Range Trail. They seem to be a good choice for the heavily utilized intersections under the prescribed site conditions. In the case of main routes that connect to low elevations and peaks, these engineering structures ensure that these main routes are solidly located.

However, for some trail segments in particularly susceptible environments, such as the steep slope of Site 3 (Refer to Appendix I), relocation may be the better solution. Trail relocation may involve several stages, and the immediate task should be to check the degradation processes before the relocation plan is finalized. Remedial measures, such as steps and drainage lines have recently been seen at that location, but these should not be viewed as the ultimate solution.

Furthermore, after trails are relocated, it is important to restrict hikers to the rerouted trails whilst protecting the degraded segments from further use, and starting rehabilitation works for the closed segments.

On gentle slopes and level ground, the problems of wide bare tread and multiple treads may be approached by defining the trail treads more clearly. Constructing scree walls (low rock walls) on both sides of the tread is a technique that has proven successful. In the mountain areas of New York, the presence of scree walls effectively contained hikers within the bordered area and make revegetation outside the tread possible. Moreover, most hikers considered the presence of the scree walls unobtrusive (Doucette & Kimball, 1990).

MONITORING TRAIL USE AND IMPACTS

Trail management has been generally reactive in nature. However, systematic monitoring is important to detect changes in condition, to set priorities and allocate funds for maintenance, and to evaluate the effectiveness of management and maintenance actions. Accordingly, the cost for management could be reduced in the long term.

Within Hong Kong country parks there is some monitoring of local trails, but it is rather subjective and descriptive, and it is used mainly for checking the facilities along the high-standard trails. A trail monitoring system needs to be more objectively designed and expanded to include the low-standard hiking routes.

A comprehensive trail impact monitoring system should comprise clearly defined management goals and corresponding standards, systematic procedures for implementation, carefully selected parameters, reliable and efficient monitoring techniques and evaluation of the monitoring effectiveness. The studies by Jim (1987a & b) on picnic sites and campsites, together with the present study on hiking trails, represent examples of study on recreation impacts in the country parks. On the basis of these studies, the current techniques of monitoring could be refined to include several easily measurable parameters which park wardens could obtain during their usual patrolling schedule. More mature monitoring systems could be referred to Cole (1989), Graefe et al. (1990) and Marion (1991).

Apart from monitoring the physical impacts of trail use, the monitoring of use characteristics and user attitudes is also important for understanding the acceptability of trail impacts and management actions. For instance, recreation impacts have been reported to decrease the satisfaction and promote the feelings of crowdiness of visitors (Lucas, 1985; Shelby & Heberlein, 1986). Furthermore, it has been reported in the western United States that wildland visitors preferred low standard trails to high standard trails (Lucas, 1980).

No information is available on the attitudes and preferences of country park visitors in Hong Kong. It seems necessary to expand the existing Country Parks Visitor Surveys (Country Parks Authority, 1988) to cover their attitudes towards recreation impacts as well as their preference and acceptability to management actions.

In a nutshell, if the conservation and recreation goals of country parks are to be pursued, degradation problems on the trails should be identified and arrested using more active management and maintenance strategies.

CHAPTER VIII

CONCLUSION

SUMMARY OF FINDINGS

The intent of the present study was to document the physical degradation and its environmental associations of a trail stretching along the ridges of the Pat Sin Range. The results indicate that the trail was generally in good condition, but the trail segments at several localities were severely degraded.

The degree of compaction, as indicated by the change of penetration resistance, was relatively low, but the inherently high level of penetration resistance of the parent material may imply an impediment to water infiltration and a greater volume of runoff on the trail tread.

Trail slope was the most significant factor in explaining most types of degradation occurring on the trail. In contrast, soil characteristics provided little explanatory power for trail morphology, yet significant relationships were established with trail tread compaction and incision.

The relationship between trail slope and compaction was found to be inverse, whilst trail slope and trail morphology had a significant positive relationship. The contrasting nature of these relationships suggest that the morphological degradation of the trail may not necessarily proceed in the similar directions, especially on steep slopes.

There was a clear difference in inherent site conditions between zones underlain by volcanic rock and those underlain by sedimentary rock. Whilst the average condition of the trail in these two geologies were found to be similar, their responses, in terms of trail degradation with respect to trail slope varied. Little association between the degradation-indicator variables and slope steepness was identifiable on the sedimentary rock slopes, but clear and usually exponential relationships were identified on the volcanic rock slopes.

The findings of this study have some implications for trail management. Trails situated on steep slopes and on regions underlain by volcanic rocks should be of concern. The sensitive response of trail condition to slope steepness calls for more careful alignment of trails on volcanic-derived soil. Other aspects of management implications from this study were explored in the preceding chapter.

LIMITATIONS OF THE STUDY

As a study conducted at one point in time, this research offers no perspective on the processes of trail degradation. Such information is important for understanding the complicated relationship between environment and trail degradation.

Moreover, the present study investigates only one of many hiking routes which are located on high elevations in the territory. The small coverage of environmental characteristics also provides only limited generalizations, and conclusive statements on the condition and environmental association of trail degradation in the territory cannot be drawn.

There were no use records for the study trail. Accordingly, the use intensity-impact relationship could not be rigorously examined. However, a more comprehensive set of data with the inclusion of use-intensity may provide substantial evidence on the role of use intensity in trail degradation.

SUGGESTIONS FOR FUTURE RESEARCH

Despite its significance to nature conservation, recreational impact research is still in its infancy in

Hong Kong. In order to safeguard the already limited park resources, investigations on every aspect of recreation impacts are needed.

For trail resources, it is apparent that research with a temporal perspective is the most pressing need for better understanding the processes of trail degradation. This type of research can be complimented by carefully-designed field experimentation.

Trail impact studies should also be expanded to other environmental settings in terms of altitude, geology, soil and vegetation communities so that the differential sensitivity of the various ecosystems in the territory can be established and compared. For instance, the process and degree of trail degradation on granitic rocks may be quite different from other types of rock in Hong Kong, due to the high erodibility of surface material. Moreover, past observation by the author suggests that the loose structure of the weathering product of granite, mainly quartz, on the trail tread could render hiker's footing unsteady in dry conditions.

Finally, research inputs on developing trail impact monitoring and assessment systems would be most beneficial to the immediate need of trail management practice, if trails are to be managed for pursuing their conservation and recreation goals in the unique context of country parks.

BIBLIOGRAPHY

(A) LITERATURE

Agriculture & Fisheries Department (1977-91), Annual Departmental Report 1976/77-1989/90, Hong Kong: Government Printer.

Aitken, R. (1985), Scottish Mountain Footpaths: A Reconnaissance Review of Their Conditon, Perth: Countryside Commission for Scotland, 97p.

Allen, S. E., H. M. Grimshaw, J. A. Parkinson & C. Quarmby (1974), Chemical Analysis of Ecological Materials, Oxford: Blackwell, pp. 13-35.

Barnes, K. K., W. M. Carleton, H. M. Taylor & others (1971), Compaction of Agricultural Soils, St. Joseph: American Society of Agricultural Engineers, 471p.

Bates, G. H. (1935), "The vegetation of footpaths, sidewalks, cart-tracks and gateways", Journal of Ecology 23: 470-87.

Bayfield, N. G. (1971), "Some effects of walking and skiing on vegetation at Cairngorm", in E. Duffey & A. S. Walt (eds.), The Scientific Management of Animal and Plant Communities for Conservation, Oxford: Blackwell, pp. 469-485.

-------- (1973), "Use and deterioration of some Scottish hill paths", Journal of Applied Ecology 10(2): 635-644.

-------- (1985), "Effects of extended use of footpaths in mountain areas of Britain", in N. G. Bayfield & G. C. Barrow (eds.), The Ecological Impacts of Outdoor Recreation on Mountain Areas in Europe and North America, Recreation Ecology Research Group Report No. 9, pp. 100-111.

-------- (1986), "Penetration of the Cairngorms Mountains, Scotland, by vehicle tracks and footpaths: impacts and recovery", in R. C. Lucas (compiler), Proceedings - National Wilderness Research Conference: Current Research, General Technical Report INT-212, Ogden: Intermountain Research Station, USDA Forest Service, pp. 121-128.

Bayfield, N.G. & R.J. Lloyd (1973), "An approach to assessing the impact of use on a long distance footpath - the Pennine Way", Recreation News Supplement 8: 11-7.

Berry, L. (1955), "Problems of soil erosion in Hong Kong", Far East Economic Review 19(3): 65-8.

Boden, R. W. (1977), "Ecological aspects of outdoor recreational planning", in D. Mercer (ed.), Leisure and Recreation in Australia, Malven: Sorrett, pp. 222-232.

Boucher, D. H., J. Aviler, R. Chepote, O. E. D. Gil & B. Vilchez (1991), "Recovery of trailside vegetation from trampling in a tropical rain forest", Environmental Management 15(2): 257-62.

Brady, N. C. (1990), The Nature and Properties of Soils, 10th Ed., New York: MacMillan, pp. 91-122.

Bratton, S. P., M. G. Hickler & J. H. Graves (1979), "Trail erosion patterns in Great Smoky Mountains National Park", Environmental Management 3(5): 431-445.

Bright, J. A. (1986), "Hiker impact on herbaceous vegetation along trails in an evergreen wildland of central Texas", Biological Conservation 36: 53-69.

Brown, J. H., S. P. Kalisz & W. R. Wright (1977), "Effects of recreational use on forested sites", Environmental Geology 1: 425-431.

Bryan, R. B. (1977), "The influence of soil properties on degradation of mountain hiking trail at Grovelsjon", Geografiska Annaler 59A: 49-65.

Burde, J. H. & J. R. Renfro (1986), "Use impacts on the Appalachian Trail", in R. C. Lucas (compiler), Proceedings - National Wilderness Research Conference: Current Research, General Technical Report INT-212, Ogden: Intermountain Research Station, USDA Forest Service, pp. 138-143.

Burden, R. F. & P. F. Randerson (1972), "Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas", Journal of Applied Ecology 9: 439-457.

Chan, K. Y. & S. W. Wu (1972), Path Effects on Vegetation. Unpublished Report, University of Hong Kong (cited by Thrower, 1975).

Chan, S. M. (1979), "Remains from ancient sea found on Pat Sin Mountain" (in Chinese), Travelling Magazine No. 166: 59-61.

Chang, H. D., B. S. Huang, Y. J. Wu and others (1989), Hong Kong Vegetation (in Chinese), Supplement to the Acta Scientiarum Naturalium Universitatis Sunyatseni No. 16, Guangzhou: Zhongshan University, 172p.

Chappell, H. G., J. F. Ainsworth, R. A. D. Cameron & M. Redfern (1971), "The effect of trampling on a chalk grassland ecosystem", Journal of Applied Ecology 8: 869-882.

Chaney, K. & R. S. Swift (1984), "The influence of organic matter on aggregate stability in some British soils", Journal of Soil Science 35: 223-230.

Chin, P. C. (1986), "Climate and Weather", in T. N. Chiu & C. L. So (eds.), A Geography of Hong Kong, 2nd Ed., Hong Kong: Oxford University Press, pp. 69-85.

Chu, K. T. (1991), Personal Communication, Chairman, The Hong Kong Federation of Countryside Activities, Hong Kong.

Cole, D. N. (1978), "Estimating the susceptibility of wildland vegetation to trailside alternation", Journal of Applied Ecology 15: 281-286.

-------- (1983a), Assessing and Monitoring Backcountry Trail Conditions, Research Paper INT-303, Ogden: Intermountain Forest & Range Experiment Station, USDA Forest Service, 10p.

-------- (1983b), Campsite Conditions in the Bob Marshall Wilderness, Montana, Research Paper INT-312, Ogden: Intermountain Research Station, USDA Forest Service, 18p.

-------- (1987), "Research on soil and vegetation in wilderness: a state-of-knowledge review", in R. C. Lucas (compiler), Proceedings - National Wilderness Research Conference: Issues, State-of-Knowledge, Future Directions, General Technical Report INT-220, Ogden: Intermountain Research Station, USDA Forest Service, pp. 135-177.

-------- (1989), Wilderness Campsite Monitoring Methods: A Sourcebook, General Technical Report INT-259, Ogden: Intermountain Research Station, USDA Forest Service, 57p.

-------- (1990), "Ecological impacts of wilderness recreation and their management", in J. C. Hendee, G. H. Stankey & R. C. Lucas, Wilderness Management, 2nd Ed., Golden: North American, Chapter 16, pp. 425-466.

-------- (1991), Changes on Trails in the Selway-Bitterroot Wilderness, Montana, 1978-89, Research Paper INT-450, Ogden: Intermountain Research Station, USDA Forest Service, 5p.

-------- (1992), Personal Communication, Wilderness Managment Research Unit, Intermountain Research Station, USDA Forest Service, Missoula, Montana, U.S.A..

Cole, D. N. & E. G. Schreiner (compilers) (1981), Impacts of Backcountry Recreation: Site Management & Rehabilitation - An Annotated Bibliography, General Technical Report INT-121, Ogden: Intermountain Forest & Range Experiment Station, USDA Forest Service, 58p.

Cole, D. N., M. E. Petersen & R. C. Lucas (1987), Managing Wilderness

Recreation Use: Common Problems and Potential Solutions, General Technical Report INT-230, Ogden: Intermountain Forest & Range Experiment Station, USDA Forest Service, 60p.

Coleman, R. A. (1981), "Footpath erosion in the England Lake District", Applied Geography 1: 121-131.

Cordell, H. K., J. C. Bergstrom, L. A. Hartmann & D. B. K. English (1990), An Analysis of the Outdoor Recreation and Wilderness Situation in the United States: 1989-2040, General Technical Report RM-189, Fort Collins: Rocky Mountain Forest & Range Experiment Station, USDA Forest Service, 113p.

Country Parks Authority (1988), Country Parks Visitor Survey Nov-Dec 1987: Summary Report, Hong Kong: Agriculture & Fisheries Department, Unpublished Report, 43p.

Cox, N. J. (1990), "Hillslope profiles", in A. S. Goudie (ed.), Geomorphological Techniques, 2nd Ed., London: Unwin Hyman, pp. 92-96.

Craig, R. F. (1987), Soil Mechanics, 4th Ed., London: Chapman & Hall, pp. 110-111.

Crawford, A. K. & M. J. Liddle (1977), "The effects of trampling on neutral grassland", Biological Conservation 12: 135-142.

Dale, D. & T. Weaver (1974), "Trampling effects on vegetation of the trail corridors of North Rocky Mountain Forests", Journal of Applied Ecology 11: 767-772.

Dawson, J. O., P. N. Hinz & J. C. Gordon (1974), "Hiking-trail impact on Iowa streamvalley forest preserves", Iowa State Journal of Research 48(4): 329-37.

DeBano, L. F. & R. M. Rice (1970), "Fire in vegetation: its effect on soil", in Proceedings - Symposium on Interdisciplinary Aspects of Watershed Management, New York: American Society of Civil Engineers, pp. 327-346.

De Ploey, J. & J. Poesen (1985), "Aggregate stability, runoff generation and interrill erosion", in K. S. Richards, R. R. Arnett & S. Ellis (eds.), Geomorphology and Soils, London: George Allen & Unwin, pp. 99-120.

Doucette, J. E. & K. D. Kimball (1990), "Passive trail management in northeastern alpine zones: a case study", in T. A. More, M. P. Donnelly, A. R. Graefe & J. J. Vaske (eds.), Proc. 1990 Northeastern Recreation Research Symposium, General Technical Report NE-145, Radnor: Northeastern Forest Experiment Station, pp. 195-202.

Durgin, P. B. (1985), "Burning changes the erodibility of forest soils", Journal of Soil & Water Conservation 40(3): 299-301.

Duffey, E. (1975), "The effects of human trampling on the fauna of grassland litter", Biological Conservation 7: 255-274.

Fish, E. B., G. L. Brothers R.B. Lewis (1981), "Erosional impacts of trails in Guadalupe Mountains National Parks, Texas", Landscape Planning 8: 387-98.

Fong-Lee M. K. (1982), How Changing Attitudes to Recreation Affect the New Territories Countryside, Occasional Paper No. 31, Hong Kong: Department of Geography, The Chinese University of Hong Kong, 50p.

-------- (1984), An Environmental Appraisal of the Popularity of Hong Kong's Country Park, Occasional Paper No. 63, Hong Kong: Department of Geography, The Chinese University of Hong Kong, 48p.

Gardiner, V. (1990), "Drainage basin morphometry", in A. Goudie (ed.), Geomorphological Techniques, 2nd Ed., London: Unwin Hyman, pp. 71-81.

Garland, G. G. (1987), "Rates of soil loss from mountain footpaths: an experimental study in the Drakensberg Mountains, South Africa", Applied Geography 7: 41-54.

Garland, G.G., C. Hudson & J. Blackshaw (1985), "An approach to the study of path erosion in the Natal Drakensberg, a mountain wilderness area", Environmental Conservation 12(4): 337-342, 335.

Gebler, C. J. (1979), "Reaching your public through television", in R. Ittner, D. Potter, J. Agee & S. Anschell (eds.), Recreational Impact on Wildlands, Conf. Proc., Publication No. R-6-001-1979, Seattle: Pacific Northwest Region, USDA Forest Service, pp. 312-313.

Geotechnical Control Office (1988), Geotechnical Area Studies Programme: North New Territories, GASP Report V, Hong Kong: Government Printer, 134p.

Goldsmith, F. B. (1974), "Ecological effects of visitors in the countryside", in A. Warren & F. B. Goldsmith (eds.), Conservation in Practice, London: John Wiley, 217-231.

-------- (1985), "Future requirements for recreation ecology research", in N. G. Bayfield & G. C. Barrow (eds.), The Ecological Impacts of Outdoor Recreation on Mountain Areas in Europe and North America, Recreation Ecology Research Group Report No. 9, pp. 162-164.

Government Information Services (1990), Country Parks of Hong Kong, Hong Kong: Government Printer, 36p.

Graefe, A. R., F. R. Kuss & J. J. Vaske (1990), Visitor Impact Management:

The Planning Framework, Washington: National Parks & Conservation Association, 106p.

Grant, C. J. (1960), The Soils and Agriculture of Hong Kong, Hong Kong: Government Printer, pp. 123-143.

Green, B. (1985), Countryside Conservation, 2nd Ed., London: George Allen & Unwin, 253p.

Grieve, I. C. (1978), Soil Aggregate Stability Tests for the Geomorphologist, British Geomorphological Research Group Technical Bulletin, 28p.

Hall, C. N. & F. R. Kuss (1989), "Vegetation alteration along trails in Shenandoah National Park, Virginia", Biological Conservation 48: 211-227.

Hammitt, W. E. & D. N. Cole (1987), Wildland Recreation: Ecology and Management, New York: John Wiley, 341p.

Hansen, A. & J. M. Nash (1985), "A brief review of soil erosion causes, effects and remedial measures", Proceedings of Conference on Geological Aspects of Site Investigation, Geological Society of Hong Kong Bulletin No. 2, Hong Kong: G.S.H.K., pp. 139-150.

Helgath, S. F. (1975), Trail Deterioration in the Selway-Bitterroot Wilderness, Research Note INT-193, Ogden: Intermountain Forest & Range Experiment Station, USDA Forest Service, 15p.

Hickler, M.G. & S.P. Bratton (1979), "Patterns of soil erosion and vegetation damage associated with trails and campsites in Great Smoky Mountains National Park", in R. Linn (ed.), Proc. Conf. on Scientific Research in the National Parks, Vol. 2, USDI National Park Service, 1261-6.

Ho, K. H. (1971), Some Geomorphological Problems of the Pat Sin Range and Adjacent Areas, North Eastern Hong Kong, Unpublished M.A. Thesis, University of Hong Kong, 110p.

Hong Kong Government (1968), The Countryside and the People: Report of the Provisional Council for the Use and Conservation of the Countryside, Hong Kong: Government Printer, 37p.

-------- (1986), Laws of Hong Kong: Country Parks Ordinance (Chapter 208), 2nd Ed., Hong Kong: Government Printer, 16p.

Hong Kong Royal Observatory (1978-91), Meteorological Results, Part I: Surface Observations 1976-90, Hong Kong: Government Printer.

Huxley, T. (1970), Footpaths in the Countryside, Perth: Countryside Commission for Scotland, 60p.

Ittner, R. (1979), "The responsible trail user", in R. Ittner, D. Potter, J. Agee & S. Anschell (eds.), Recreational Impact on Wildlands, Conf. Proc., Publication No. R-6-001-1979, Seattle: Pacific Northwest Region, USDA Forest Service, pp. 320-321.

Kemper, W. D. (1965), "Aggregate stability", in C. A. Black (ed.), Methods of Soil Analysis, Vol. 1, Madison: American Society of Agronomy, pp. 511-519.

Jim, C. Y. (1986), "The country parks programme and countryside conservation in Hong Kong", The Environmentalist 6(4): 259-270.

-------- (1987a), "Camping impacts on vegetation and soil in a Hong Kong country park", Applied Geography 7: 317-332.

-------- (1987b), "Trampling impacts of recreationists on picnic sites in a Hong Kong country park", Environmental Conservation 14(2): 117-127.

-------- (1987c), "Country park usage and visitor impacts in Hong Kong", Parks 12(1): 3-8.

-------- (1989a), "Changing patterns of country-park recreation in Hong Kong", Geographical Journal 155(2): 167-178.

-------- (1989b), "Country parks and outdoor recreation in Hong Kong", in C. K. Leung, C. Y. Jim & D. K. Zuo (eds.), Resources, Environment and Regional Development, Hong Kong: Centre of Asian Studies, University of Hong Kong, pp. 219-260.

Jubenville, A. & K. O'Sullivan (1987), "Relationship of vegetation type and slope gradient to trail erosion in interior Alaska", Journal of Soil & Water Conservation 42(6): 450-452.

Ketchledge, E H. & R. E. Leonard (1970), "The impact of man on the Adirondack high country", The Conservationist 25(2): 14-18.

Kuss, F. R. (1986a), "The effect of two hiking intensities on wildland trail wear", in R. C. Lucas (compiler), Proceedings - National Wilderness Research Conference: Current Research, General Technical Report INT-212, Ogden: Intermountain Research Station, USDA Forest Service, pp. 158-165.

-------- (1986b), "A review of major factors influencing plant reponses to recreation impacts", Environmental Management 10(5): 637-650.

Kuss, F. R. & J. M. Morgan (1984), "Using the USLE to estimate the physical carrying capacity of natural areas for outdoor recreation planning", Journal of Soil and Water Conservation 39(6): 383-386.

Kuss, F. R., A. R. Graefe & J. J. Vaske (1990), Visitor Impact Management:

A Review of Research, Washington: National Parks & Conservation Association, 256p.

Lal, R (1988), "Erodibility and erosivity", in R. Lal (ed.), Soil Erosion Research Methods, Ankeny: Soil and Water Conservation Society, pp. 141-160.

-------- (1992), "Restoring land degraded by gully erosion in the tropics", in R. Lal & B. A. Stewart (eds.), Soil Restoration, Advances in Soil Science No. 17, New York: Springer-Verlag, pp. 123-152.

Lance, A. N., I. D. Baugh & J. A. Love (1989), "Continued footpath widening in the Cairngorm Mountains, Scotland", Biological Conservation 49: 201-214.

Lau, S. M. (1991), "Strategic planning: a land use framework for conservation", in J. Boxall (ed.), Conference Proceedings - POLMET 1991, Hong Kong: Hong Kong Institute of Engineers, pp. 889-898.

Law, T. W. (1983), "A good resort for hiking - the Pat Sin Range" (in Chinese), Country Life Magazine No. 4: 30-33.

Lay, C. C. (1990), Personal Communication, Country Parks Management Officer, Agriculture & Fisheries Department, Hong Kong Government.

Leonard, R. E. (1979), "Protecting the long trail resource: a problem analysis", in W. R. Burch, Jr. (ed.), Long Distance Trails: The Appalachian Trail as a Guide to Future Research and Management Needs, New Haven: School of Forestry & Environmental Studies, Yale University, pp. 84-103.

Leonard, R.E. & A.M. Whitney (1977), Trail Transect: A Method for Documenting Trail Changes, Research Paper NE-389, Upper Darby: Northeastern Forest Experiment Station, USDA Forest Service, 8p.

Leonard, R. E., J. L. McMahon & K. M. Kehoe (1985), Hiker Trampling Impacts on Eastern Forests, Research Paper NE-555, Broomall: Northeastern Forest Experiment Station, USDA Forest Service, 5p.

Liddle, M. J. (1988), Recreation and the Environment: The Ecology of Recreation Impacts, Section 2: Vegetation and Wear, AES Working Paper 1/88, Nathan: Division of Australian Environmental Studies, Griffith University, 189p.

-------- (1989), Recreation and the Environment: The Ecology of Recreation Impacts, Section 3: Soils and Wear, AES Working Paper 1/89, Nathan: Division of Australian Environmental Studies, Griffith University, 235p.

-------- (1991), "Recreation ecology: effects of trampling on plants and corals", Trends in Ecology and Evolution 6(1): 13-17.

--------- (1992), Personal Communication, Division of Australian Environmental Studies, Griffith University, Brisbane, Australia.

Liddle, M. J. & P. Greig-Smith (1975), "A survey of tracks and paths in a sand dune ecosystem, I. Soil", Journal of Applied Ecology 12: 893-908.

Lucas, R. C. (1980), Use Patterns and Visitor Characteristics, Attitudes and Preferences in Nine Wilderness and Other Roadless Areas, Research Paper INT-253, Ogden: Intermountain Research Station, USDA Forest Service, 89p.

-------- (Senior Author) (1984), "Outdoor recreation management", in K. F. Wenger (ed.), Forestry Handbook, 2nd Ed., New York: John Wiley, pp. 801-885.

-------- (1985), Visitor Characteristics, Attitudes and Use Patterns in the Bob Marshall Wilderness Complex, 1970-82, Research Paper INT-345, Ogden: Intermountain Research Station, USDA Forest Service, 32p.

-------- (1990), "Wilderness recreation management: a general overview", in J. C. Hendee, G. H. Stankey & R. C. Lucas, Wilderness Management, 2nd Ed., Golden: North American, Chapter 15, pp. 401-422.

Marion, J.L. (1986), "Campsite impact assessment systems: application, evaluation, and development", in J.S. Popadic et al. (eds.), Proc. 1984 Nat. River Recreation Symp., Baton Ronge: Sch. Lands. Arch., Louisiana State Univ., 561-73.

-------- (1991), Developing a Natural Resource Inventory and Monitoring Program for Visitor Impacts on Recreation Sites: A Procedural Manual, Natural Resources Report NPS/NRVT/NRR-91/6, Denver: USDI National Park Service, 59p.

Marion, J. L. & L. C. Merriam (1985), Recreational Impacts on Well-Established Campsites in the Boundary Waters Canoe Area Wilderness, Station Bulletin AD-SB-2502, St Paul: Agricultural Experiment Station, University of Minnesota, 16p.

Marion, J. L. & D. N. Cole (1989), "Recreation impact research: a multi-faceted design", Park Science 9(1): 23-24.

Matheny, S. J. (1979), "A successful campaign to reduce trail switchback shortcutting", in R. Ittner, D. Potter, J. Agee & S. Anschell (eds.), Recreational Impact on Wildlands. Conf. Proc., Publication No. R-6-001-1979, Seattle: Pacific Northwest Region, USDA Forest Service, pp. 217-220.

McRae, S. G. (1988), Practical Pedology, Chichester: Ellis Horwood, pp. 37-65.

More, T. A. (1980), Trail Deterioration as an Indicator of Trail Use in an

Urban Forest Recreation Area, Research Note NE-292, Broomall: Northeastern Forest Experiment Station, USDA Forest Service, 4p.

Morgan, R. P. C. (1985), "The impact of recreation on mountain soils: towards a predictive model for soil erosion", in N. G. Bayfield & G. C. Barrow (eds.), The Ecological Impacts of Outdoor Recreation on Mountain Areas in Europe and North America, Recreation Ecology Research Group Report No. 9, pp. 112-121.

--------- (1986), Soil Erosion and Conservation, Essex: Longman, 298p.

Ng, P. P. T. (1986), Recent Trends in Work and Leisure in Hong Kong and Higher Education's Response, Occasional Paper No. 13, Hong Kong: Centre for Hong Kong Studies, The Chinese University of Hong Kong, 38p.

Petersen, R. G. & L. D. Calvin (1965), "Sampling", in C. A. Black (ed.), Methods of Soil Analysis, Vol. 1, Madison: American Society of Agronomy, pp. 54-72.

Pounder, E. J. (1985), "The effects of footpath development on vegetation at the Okstindan Research Station in arctic Norway", Biological Conservation 34: 273-288.

Proudman, R. D. & R. Rajala (1981), AMC Field Guide to Trail Building and Maintenance, 2nd Ed., Boston: Appalachian Mountain Club, 286p.

Quinn, N. W., R. P. C. Morgan & A. J. Smith (1980), "Simulation of soil erosion induced by human trampling", Journal of Environmental Management 10(2): 155-165.

Richards, K. S. (1990), "River channel form", in A. S. Goudie (ed.), Geomorphological Techniques, 2nd Ed., London: Unwin Hyman, pp. 82-91.

Root, J. D. & L. J. Knapik (1972), Trail Conditions along a Portion of the Great Divide Trail Route, Alberta and British Columbia Rocky Mountains, Report No. 72-5, Edmonton: Research Council of Alberta, 24p.

Shelby, B. & T. A. Herbelein (1986), Carrying Capacity in Recreation Settings, Corvallis: Oregon State University Press, pp. 43-72.

Siegel, S. & N. J. Castellan (1988), Nonparametric Statistics for the Behavioral Sciences, 2nd Ed., New York: McGall-Hill, 399p.

Slaughter, C. W., C. H. Racine, D. A. Walker, L. A. Johnson & G. Abele (1990), "Use of off-road vehicles and mitigation of effects in Alaska permafrost environments: a review", Environmental Management 14(1): 63-72.

Speight, M. C. D. (1973), Outdoor Recreation and Its Ecological Effects, Discussion Papers in Conservation No. 4, London: University College, 35p.

Starodubova, V. A. (1985), "effect of recreational activities on soil properties in the Crimean Mountains", Soviet Soil Science 17(3): 94-98.

Sum, K. F. (1980), The Path Effect in Scrubland, Unpublished Seminar Report, Department of Biology, The Chinese University of Hong Kong, 55p.

Summer, R. M. (1980), "Impact of horse traffic on trail in Rocky Mountain National Park", Journal of Soil & Water Conservation 35(2): 85-87.

-------- (1986), "Geomorphic impacts of horse traffic on montane landforms", Journal of Soil & Water Conservation 41(1): 126-128.

Talbot, L. M. & M. H. Talbot (1965), Conservation of the Hong Kong Countryside: Summary Report and Recommendation, Hong Kong: Government Printer, 34p.

Thrower, L. B. (1975), "The vegetation of Hong Kong", in L.B. Thrower (ed.), The Vegetation of Hong Kong: Its Structure and Change, Hong Kong: Royal Asiatic Society Hong Kong Branch, pp. 21-43.

Thrower, S. L. (1984), Hong Kong Country Parks, Hong Kong: Government Printer, 216p.

Tinsley, B. E. & E. B. Fish (1985), "Evaluation of trail erosion in Guadalupe Mountains National Parks, Texas", Landscape Planning 12: 29-47.

Wall, G. & C. Wright (1977), The Environmental Impact of Outdoor Recreation, Publication Series No.11, Waterloo: Department of Geography, University of Waterloo, 69p.

Ward, R. M. & R. C. Berg (1973), "Soil compaction and recreational use", Professional Geographer 25(4): 369-372.

Weaver, T. & D. Dale (1978), "Trampling effects of hikers, motorcycles and horses in meadows and forests", Journal of Applied Ecology 15: 451-457.

Welch, D. M. & J. Churchill (1986), Hiking trail conditions in Pangnirtung Pass, 1984, Baffin Island, Canada, Parks Canada Report, Ottawa: Parks Canada, 19p.

Whittaker, P. L. (1978), Comparison of Surface Impact by Hiking and Horseback Riding in the Great Smoky Mountains National Park, Research/Resources Management Report No. 24, Gatlinburg: Southeast Region, USDI National Park Service, 32p.

Wholey, J. W. (1978), "The Hong Kong countryside and its importance to the community", in R. D. Hill & J. M. Bray (eds.), Geography and the Environment in Southeast Asia, Hong Kong: Hong Kong University press, pp. 345-352.

Wong, F. Y. (1988), "Recreation planning in country parks", Planning & Development 4(2): 62-68.

-------- (1991), Personal Communication, Senior Development Officer, Agriculture & Fisheries Department, Hong Kong Government.

Young, R. A. & C. K. Mutchler (1969), "Effect of slope shape on erosion and runoff", Transactions A.S.A.E. 12(1): 231-3, 239.

(B) MAPS

Geotechnical Control Office, Civil Engineering Services Department (1991), Hong Kong Geological Survey - Solid and Superficial Geology: Sheung Shui (Sheet 3) (Scale 1:20000), Series HGM20.

Lands & Survey Department, Public Works Department (1976), Sheung Shui (Sheet 3) (Scale 1:20000), Series HM20C, 1st Edition.

-------- (1980), Sheung Shui (Sheet 3) (Scale 1:20000), Series HM20C, 2nd Edition.

Survey Division, Lands Department (1985), Sheung Shui (Sheet 3) (Scale 1:20000), Series HM20C, 3rd Edition.

Survey & Mapping Office, Buildings & Lands Department (1987), Sheung Shui (Sheet 3) (Scale 1:20000), Series HM20C, 4th Edition.

-------- (1991), Countryside Series: North-East New Territories (Scale 1:25000), 3th Edition.

(C) NEWSPAPERS

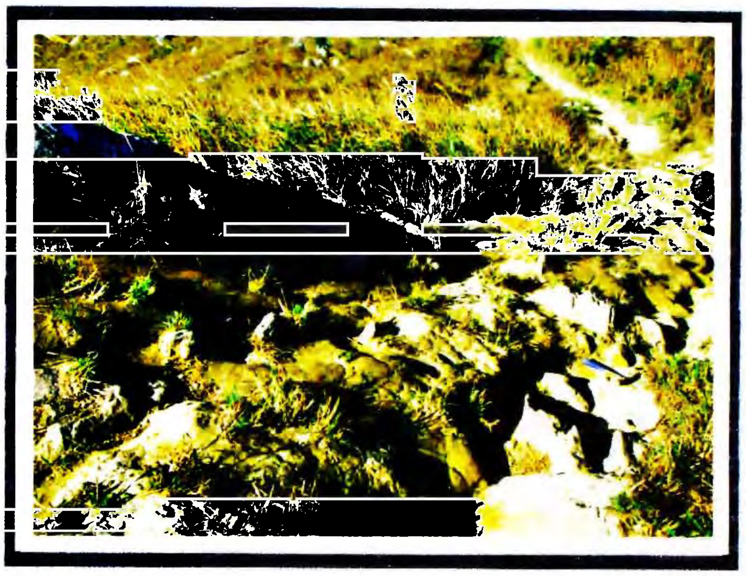
South China Morning Post, 27th June, 1992.

APPENDIX

DESCRIPTIONS OF SELECTED DEGRADED SITES

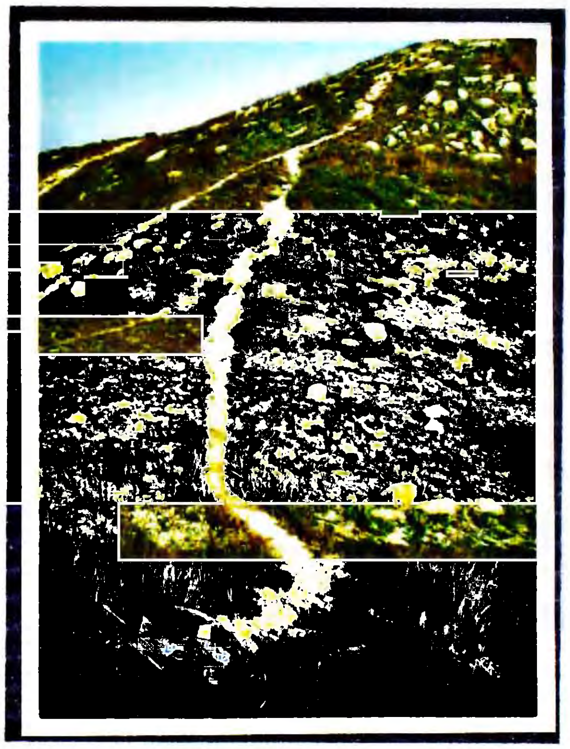
Site: 3
DEG=5.81 (Rank 1)

Location: Sheung Tsz Fung, Pat Sin Leng
Rock: Volcanic
Position: DA-Upper Slope
Trail Slope: 33.56°
Major Problems:
(1) wide tread - 670cm
(2) deep incision - 26cm
(3) soil loss - 4171cm^2
(4) multiple treads
Probable Cause:
Steep trail slope
Management Recommendation:
Remove trail from slope



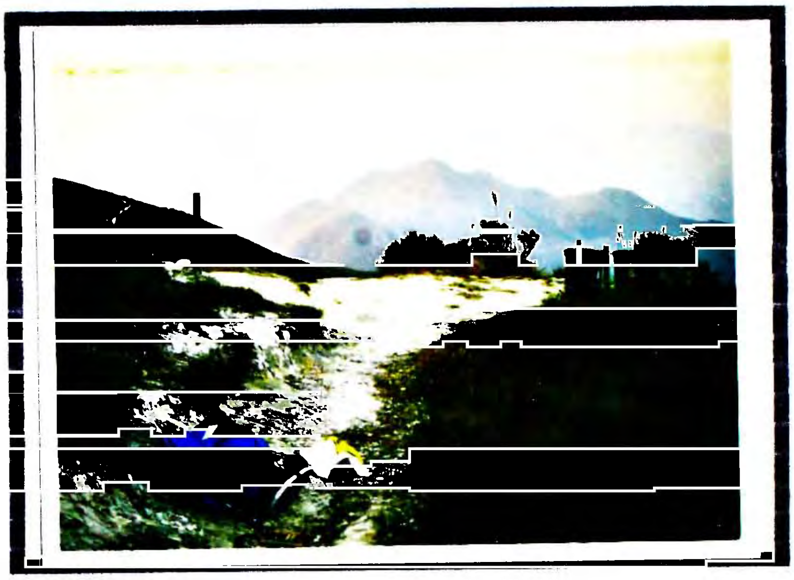
Site: 41A
DEG=1.11 (Rank 2)

Location: Ping Fung Shan
Rock: Sedimentary
Position: DA-Lower Slope
Trail Slope: 21.11°
Major Problems:
(1) deep incision - 26cm
(2) soil loss - 907cm^2
(3) shortcuts
Probable Cause:
Steep trail slope
Management Recommendation:
Level tread and place water bar



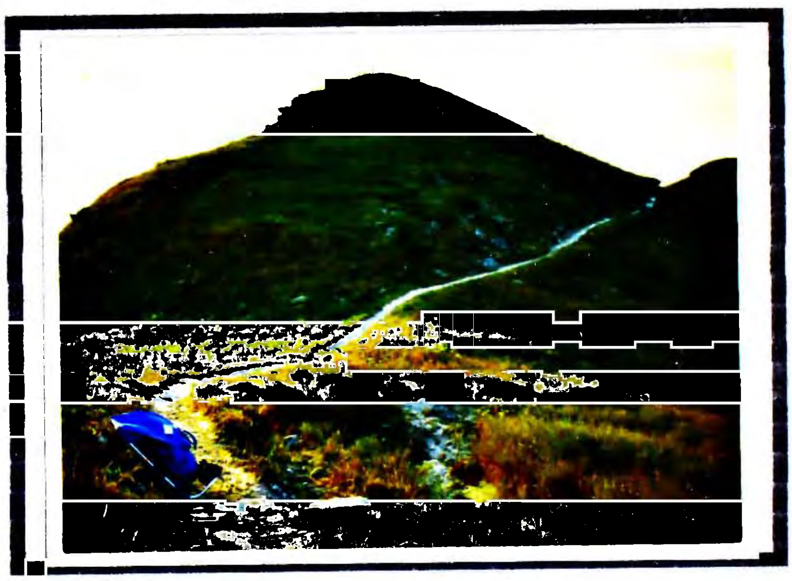
Site: 44
DEG=0.71 (Rank 4)

Location: Ping Fung Shan
Rock: Sedimentary
Position: OB-Sidehill
Trail Slope: 5.39^{o}
Major Problems:
(1) deep incision - 15cm
(2) soil loss - 1049cm^{2}
Probable Cause:
Near trail junction
Management Recommendation:
(1) Level tread
(2) harden backslope



Site: 33
DEG=0.70 (Rank 5)

Location: Near Wong Leng
Rock: Sedimentary
Position: LV-Valley Floor
Trail Slope: 8.61^{o}
Major Problems:
(1) wide tread - 228cm
(2) multiple treads
Probable Cause:
Switchback
Management Recommendation:
Education/Interpretation



Site: 32
DEG= 0.59 (Rank 6)

Location: Wong Leng
Rock: Sedimentary
Position: OB-Sidehill
Trail Slope: 6.83°
Major Problems:
(1) deep incision - 20cm
(2) too narrow tread - 51cm
Probable Cause:
Steep sideslope
Management Recommendation:
fill incised tread

Site: 40A
DEG=0.13 (Rank 17)

Location: Ping Fung Shan
Rock: Sedimentary
Position: DA-Interfluve
Trail Slope: 8.89°
Major Problems:
multiple treading
Probable Causes:
(1) sightseeing at both sides
(2) gentle sideslopes
Management Recommendation:
Education/Interpretation